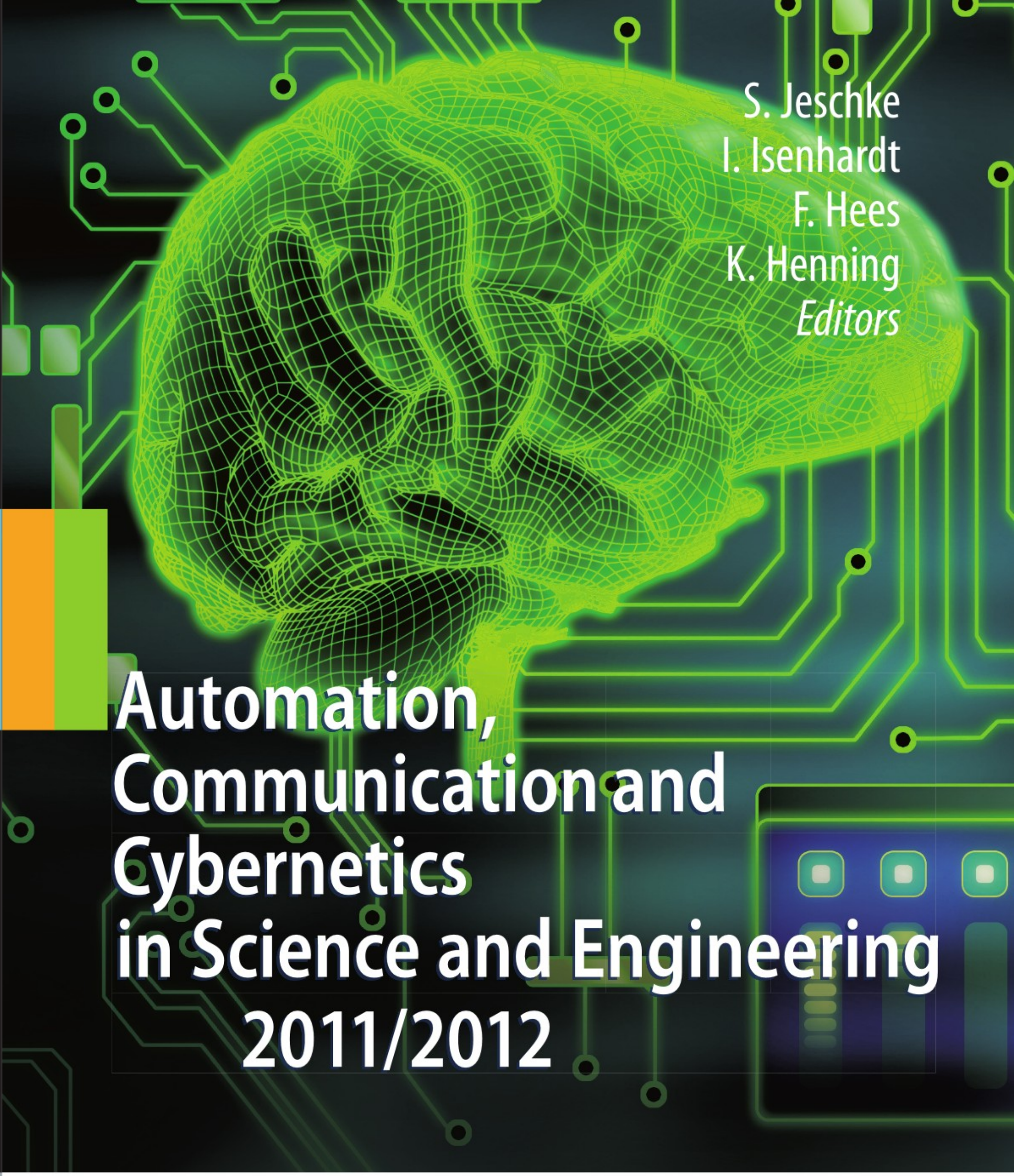

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Automation, Communication and Cybernetics in Science and Engineering 2011/2012

RWTH AACHEN UNIVERSITY

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Foreword

Dear Reader,

We are very pleased to present you the second book of our new series of the institute cluster IMA/ZLW & IfU named "Automation, Communication and Cybernetics 2011/2012". As is the characteristics of the series, this anthology brings together our scientifically diverse and widespread publications over a time period of 24 months (July 2010–June 2012). Almost all publications are peer-reviewed and have been published in recognized journals or conference proceedings of the various disciplinary cultures. In spring 2011 we changed the organizational structure of our institute cluster IMA/ZLW & IfU.

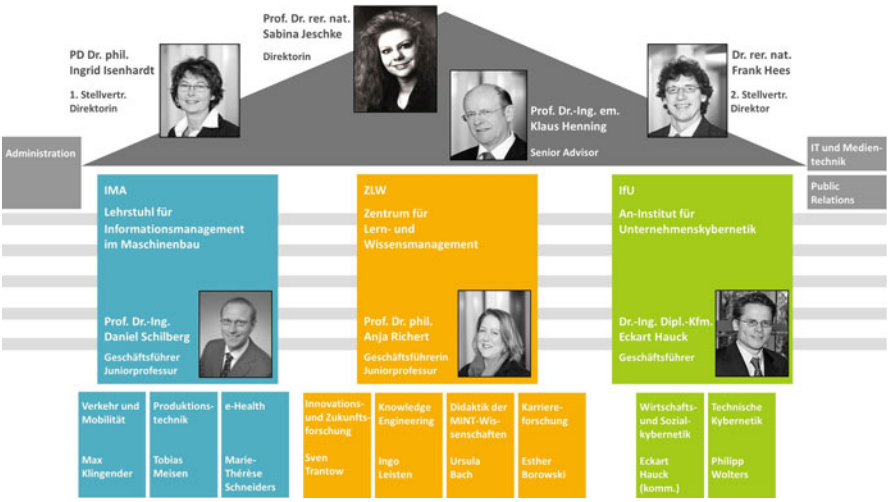

Fig. 1 Organizational structure of the institute cluster IMA/ZLW & IfU, RWTH Aachen University

After many successful years with a two-staged managing structure consisting of institute and division directors, the structure was changed on the 1^{st} of April to a three-staged one – heads of institute, managing directors and research group leaders. There are many reasons for this reorganization, but the three main motives are: growth potential, implementation of a comprehensive PostDoc strategy and the focus of the research profile of the institute cluster.

The scientific core of the Institute of Information Management in Mechanical Engineering – IMA consists of three research groups:

- The aim of the research group "**Production Technology**" is to implement modern information technology concepts into production technology by combining skills of engineering and computer science as well as mathematics and sociology. A main focus of the research group is the development of methods and tools to integrate heterogeneous sensors, simulation and application data and to enable a consolidated and consistent analysis. The so called Virtual Production Intelligence makes use of these methods and tools to facilitate the transfer of information between human, machine and technology. Another focus of the research activity is the development of barrier-free user interfaces for web and automation systems. The aim is a user-centered software development process supporting the requirements of accessibility for users with disabilities or limited technology. Furthermore the research group addresses the integration of intelligent controls in technical production systems. Therein scientific findings from artificial intelligence, knowledge-based systems and cognitive research are adapted and optimized for the application field "production technology".
- The research group "**Traffic and Mobility**" is working on solutions for accident-free driving, on the multimodal freight traffic of the future and on barrier-free mobility. In doing so, the interdisciplinary team includes current requirements like a higher resource efficiency and improved user integration into their solutions. Thereby competences of different disciplines are combined such as engineering science, computer science, sociology and economics. The research activities of the group "Traffic and Mobility" lead to concrete solution hypothesises for these solutions. The vision of accident-free driving could be achieved by heterogeneous networks of (semi-)automated vehicles. To reach the ideal of efficient freight traffic of the future, modular, worldwide usable loading units with appropriate transport carriers could be utilized. The applied methods of the research group range from driving simulation over dual design and acceptance/stress analysis up to the holistic consideration of the three recursion dimensions: human, organization and technology. The activities of the research group include the research and development of new technologies as well as the development of methods and tools for the product development process in the above mentioned application fields.
- The research group **eHealth** consists of engineers, economists as well as human and social scientists who research and develop information technology based

on solutions for medical care. Developing telematic support systems which are especially used in emergency medical services, the research group focuses on approaches of user-centred requirement management and develops appropriate system architectures as well as software solutions for the display of information. At the same time aspects of IT security risk management are considered and controlled. Another research focus is the scientific analysis of implementation processes of technologies and the use of prototypes in complex field tests.

The Center for Learning and Knowledge Management – ZLW started with four research groups:

- The research group "**Knowledge Engineering**" addresses the interaction between data – information – knowledge on the levels individual, team, organization, network and society. Thereto structures and processes are modeled and implemented which support and develop communication and cooperation. This application-oriented research leads to services and products, whereby customers and users are integrated iteratively and cooperatively into the solution process. The simultaneous design of the dimensions Human-Organisation-Technology enables a holistic, tailor made and systematic approach. Current fields of action include management and governance of clusters, diversity management in innovation processes and in the organization of work, measurement of performance as well as intellectual capital. Moreover, technical aspects of knowledge management such as semantic search and the design of (multimedia) learning environments are focused. The research group also provides consulting, moderation and coaching in organizational and strategy development as well as cooperation design and knowledge management.
- The research group "**Innovation Research and Futurology**" analyzes the socio-economic trends, opportunities and challenges of tomorrow's world of economy and work. Based on this knowledge, target-group-specific and practice-orientated concepts are developed to enable organizations, networks and teams to generate innovations and thus to ensure sustainable competitiveness. In doing so, all kinds of innovations are considered systematically, i.e. as complex interrelations between the dimensions human, organization, and technology. The development of customized and individual communication concepts allows an efficient transfer of research knowledge into economic practice. The research group provides support for scientific, economic and political organizations as well as individuals in the following topic areas: sustainable establishment and fostering of innovative capacity, monitoring of trends and foresight, holistic innovation management, organizational as well as communication development, support of social and organizational innovations, intellectual capital and knowledge balancing as well as transfer of knowledge and communication management.
- In an interdisciplinary team of communication and political scientists, engineers, sociologists and economic geographers the research group "**Didactics in STEM Fields**" is dealing with challenges of didactics, especially those of the STEM

Fields, including mathematics, computer sciences, engineering and technics. To prove successful didactic concepts during its development, the involvement of every actor actively participating in education is needed. Therefore the groups of tutors, students, employers, intermediate organizations and other experts on university didactics, are integrated in our research activities.
- The interdisciplinary research group "**Career Research**" addresses the development and active organization of careers in research and industry. A special research focus is on the academic career and its further development in university and beyond as well as in the industrial context. Moreover, prevalent career structures, aspects of diversity as well as careers in different disciplines are focused. The research group "Career Research" also analyses the individual development of competences, especially the development of junior scientific staff and offers the continuous qualification of the scientific staff of the RWTH Aachen University for quality assurance in research and teaching.

The Associated Institute for Management Cybernetics e.V. – IfU used the opportunity to extend its research focus once more:

- The research team "**Economic and Social Cybernetics**" deals with cybernetic methods and tools for the industrial practice. We develop solutions for complex problems in conjunction with industrial and research partners. In interdisciplinary research projects our rudiments are directly converted and evaluated by the involved companies. The focus is on analysing organizations with the aid of system models and the development of valuation methods to endorse decisions for example in investment or reorganization projects. Furthermore, the team deals with the development of operating business games which are used for the development and support of change processes. In conjunction with the research team of Technical Cybernetics these business games are technically converted.
- The research team "**Technical Cybernetics**" is a part of the Institute for Management Cybernetics at the RWTH Aachen University. It deals with the research and the development of technical solutions for complex systems. The focus is on controlling autonomous systems, cooperative robotics, technical implementation of business games and the optimization of complex systems in general. We explore how technical systems observe their environment through suitable sensory and how they may react on the environment through control loop based algorithms. Therefore, the research group focuses not only on individual and homogenous systems, but also on automated communication and coordination of heterogeneous systems. The harmonious cooperation of human and technology is a very important aspect. It plays an important role with regard to business games. Here the research team "Technical Cybernetics" deals with the development of platforms to facilitate integratively knowledge contents.

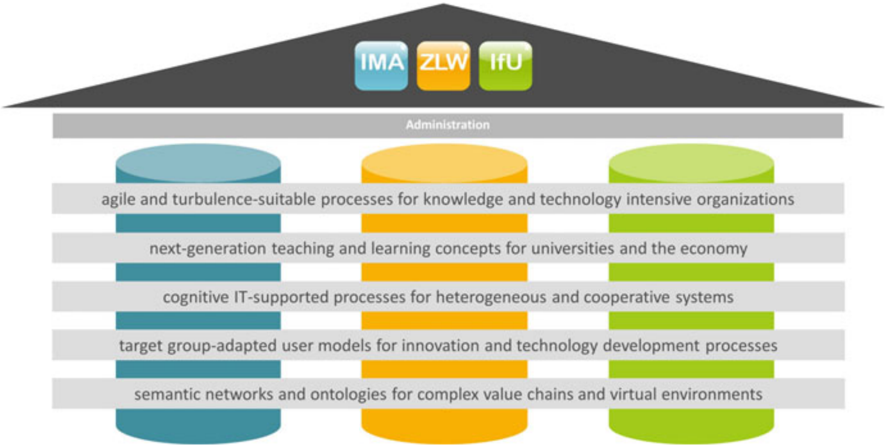

Fig. 2 The research fields across the institute cluster

As depicted in the upper matrix we maintained the concept of research fields that run across the institutes – horizontal to our organizational structure. These fields combine our competences in our interdisciplinary institute cluster and help us to structure the topics presented in this book. Our special appreciation goes to our team. It is their dedication, their passion, their scientific curiosity und last not least their dauntlessness which make this institute cluster to what it is.

Aachen, August 2012

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Part I
Agile and Turbulence-Suitable Processes for Knowledge and Technology Intensive Organizations

I Know Something, that You Do Not Know
Transfer in the Research Field Occupational Health and Safety

Ursula Bach, Ingo Leisten

Abstract Research on Occupational Health and Safety can look back on a long history. Unfortunately, the results of this research are not manifested in public consciousness. Today, the biggest challenge to a scientist is to guarantee successful transfer between the research field "Occupational Health and Safety" and the actors in the sphere of practice. We cannot face the challenge by producing still more knowledge and research results, instead we need to restructure the whole transfer and the process of researching. In German research you may find different best practice that helps to optimize knowledge management. These best practices build on a new understanding of knowledge transfer, so called "transfer engineering", and make use of systems theory and network management. Thus, research plans are structured in a novel manner, utilizing instruments of transfer in breadth and depth between scientists and practitioners and raising the visibility of a funding priority through its joint efforts on a topical core. These instruments of network management and transfer engineering will be the topic of this paper.

Key words: Occupational Health and Safety Research, Transfer, Knowledge Engineering

1 Introduction

Innovative research structures provide a possibility to better address and appeal to new stakeholders within the topic of Preventive Occupational Health and Safety, as for example health insurance, chambers of commerce or ministries. This means visibility of the research community can be increased at the network and society level. To reach the goals "better visibility of the research community", "improving

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integration of partners within research groups" and "avoidance of 'fragmenting' of a research community", the founding priority Preventive Occupational Health and Safety applied different network management methods [HLBH09]. The choice of network management methods is based on the needs of a research network in three specific network phases: phase of initiation, phase of stabilization and finally the phase of permanence. Every phase offers different challenges to network management. To support the efforts of the network, a transfer project was initialized. This special research meta-project StArG (Strategischer Transfer im Präventiven Arbeits- und Gesundheitsschutz, engl. Strategical Transfer in the field of Preventive Occupational Safety and Health) provided research results on transfer in breadth and depth for network management and research communication.

2 Stakeholders of Preventive Occupational Health and Safety and Transfer in Breadth

Transfer in breadth is an important factor as it centers on the stakeholders of Preventive Occupational Health and Safety. The goal of transfer in breadth is to steer public discussion towards the need for Preventive Occupational Health and Safety to be integrated into entrepreneurial practice and thus to point out the need for action to the individual enterprises. According to Freeman [Fre84], the term "stakeholder" is defined as "any group or individual who can affect or is affected by the achievement of a [corporation's] purpose". The influence of the individual groups of stakeholders is strongly dependent on the framework conditions within the individual enterprise/project as well as on the interaction between the individual stakeholder groups [Bal]. Within Preventive Occupational Health and Safety, stakeholders are e.g. branch-specific and inter-branch interest groups and associations, public and political institutions, health insurance funds and companies or trade and workers' unions. All of these stakeholders have requirements and demands towards enterprises and their measures on Preventive Occupational Health and Safety. In order to design a target-oriented transfer in breadth, we have to identify such stakeholder groups as are individually relevant. Special efforts have to be made to incorporate intermediaries into the transfer process to make use of their potential to achieve a lasting awareness of the notion of prevention in all stakeholders. Measures for transfer in breadth should be aimed at these stakeholder groups to raise their awareness for requirements in the area of prevention and thus to strengthen their positions. Figure 1 shows examples of stakeholders and their requirements in Preventive Occupational Health and Safety. Enterprises will have to identify these stakeholders against the enterprise-specific framework conditions.

Embedding the notion of prevention into an enterprise is effected by matching enterprise-specific design components. The integration into business procedures and structures of aspects relevant to prevention necessitates redesigning the components of the social system consisting of the individual person, organization, technology, information, tasks, decision system, rewards and supervision [HM]. Here, all de-

Fig. 1 Depiction of new actor and institutional constellations based on the Transfer Diagnostic Workshops held by the StArG meta-project

sign components are verified regarding their relevance for Preventive Occupational Health and Safety and adjusted where necessary. As the individual design components are heavily cross-linked, an adequate complexity dimensioning of the components among themselves must be achieved [SH92]. Successful transfer in breadth of Preventive Occupational Health and Safety addresses enterprise-specific stakeholders at this very point. This is why the central task of actors within Preventive Occupational Health and Safety is to identify the individual stakeholders and to sensitize them through methods of transfer in breadth.

3 Research Network Preventive Occupational Health and Safety

3.1 Research Networks and Their Requirements

When choosing its management methods, the funding priority understood itself as a research network, as it shows network-specific characteristics. Network theory gives four characteristics research networks have to feature in order to be referred to as such [Jan04].

1a) Research networks consist of several individually disjunct network partners.
2a) These network partners are related through regulated prearrangements.
3a) The network partners have the possibility to use synergies, e.g. through resource sharing or knowledge exchange.
4a) The network partners have a technological or social subsystem.

Regarding the research network Preventive Occupational Health and Safety, these four characteristics can be translated as follows:

1b) The research network "Preventive Occupational Safety and Health" consists of 18 joint research projects and nine individual research projects that work on diverse research outcomes and approaches within various research institutions and enterprises from diverse scientific disciplines [the09].
2b) The content-related relationships of the various projects are regulated through the composition of the focus groups. The relationships built through the funding priority and supported by regular events are initiated, organized and carried out by the meta-project (for an overview on the activities of the funding priority see www.starg-online.de).
3b) The individual network and research partners have a multitude of possibilities to use resources within the funding priority, e.g. through joint surveys and synergetic public relations work or through annual conferences that serve as a platform for joint scientific work on topics of "Preventive Occupational Health and Safety".
4b) The social sub-system of the research network is created by the structures of the funding priority. The technological sub-system is created among others through the interactive exchange and discussion platform as well as through the material resources of the individual projects.

The following goals are generally intended when initiating research networks: Better integration of the joint research participants and "avoidance of 'fragmentation'" of a research community [Hue03]. In joint research, a better integration generally means a better cooperation between science and entrepreneurial practice. In the case of the funding priority "Preventive Occupational Health and Safety" broader-ranging aims are intended: To contribute to the competitive ability of German economy, to counter economic losses through insufficient preventive occupational health and safety measures and to stay abreast of changes in the modern work environment [BMB09].

The choice of network management methods thus has to allow for the project goals as well as the necessities of a research network during the individual network stages.

According to Ahrens et al. [Aea04], a research network, once approved, runs through three stages: the initiating phase, the stabilizing phase and the permanent phase. The initiating phase lays the foundations for joint work. Here, mutual trust is established and first attunements are made regarding thematic decisions, division of labor or structural agreements. The stabilizing phase is the most productive stage of a network. The chances for utilizing resources have become clear and trust can

Table 1 Own compilation of the phases and their requirements for a network management of the funding priority according to Ahrens D. et al. [Aea04]

Phases	Requirements
Initiating phase	– Choice of projects, – Composition of focus groups, – Matching expectations and values that are to be the foundations of joint efforts, – Settling the means of exchange within the thematic superstructure of the focus group, – Attunement of task and resource allotments, – Assigning individual tasks and resources.
Stabilizing phase	– Create possibilities to build trust beyond the activities of the first stage, – Work out a mutual understanding of the research matter, – Synergies are being recognized and made use of, e.g. through joint surveys of research results.
Permanent phase	– Securing a sustained impact of research results, – Expansion of the network, – Funding-priority-internal securing of results for funding-priority-external transfer, – Provide appropriability of the funding priority's results, – Work out visions for the future of the funding priority.

be deepened. In the permanent phase, the actual work of the network is heading toward the end and results have to be secured, processed and made available for subsequent stages (for an elaboration see [OH04]). Within the third phase, research networks with private and/or public funding have to pay special attention to later utilization of their projects' results [BMB06]. Leisten further suggests keeping appropriability in view across all of the research process [HLB09]. When designing research networks, it has to be noted that these phases rarely ever occur in stringently chronologic succession but rather tend to overlap, repeat themselves or get abandoned. Thus, every phase poses different challenges to network management (summarized in Table 1).

3.2 Diagnosis of the Research Network Preventive Occupational Health and Safety

Besides knowledge of the individual stages a diagnosis of the research network is necessary to facilitate strategic management. This diagnosis is structured along five lines: Structure of actors, communication and interactions, development and renewing, controlling, and the material equipment of the projects and focus groups.

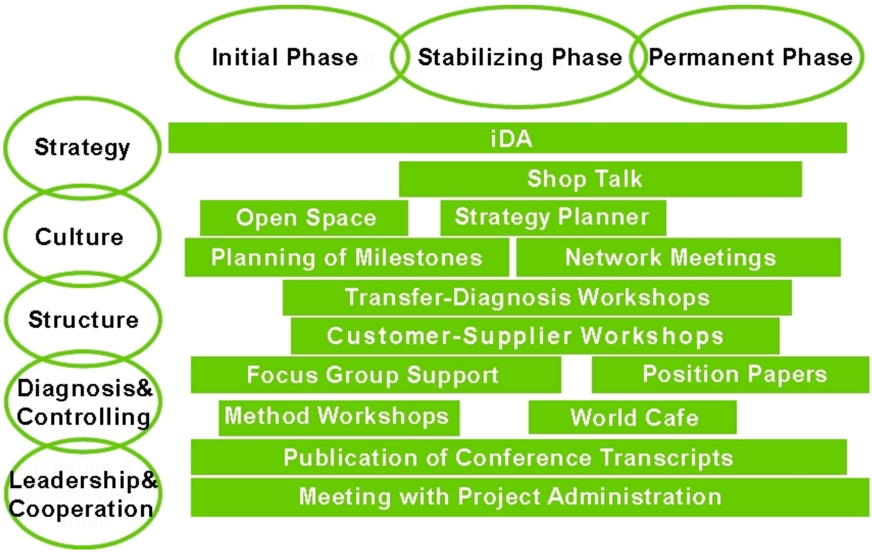

Fig. 2 A variety of possible management methods and network services within the funding priority with consideration to the phases and design elements

The Actor line describes e.g. what projects are part of the funding priority, which value partners are integrated into the research processes or what focus groups have been initiated, as the individual projects and their staff lend different scientific skills and experiences as well as new contacts to the Preventive Occupational Health and Safety community [LNAF04]. The line of communication and interactions depicts what ways of communication are used and what sorts of interaction are possible between the actors, e.g. team work or virtual meetings. Development and renewing shows the innovative potential of the research network. Controlling contains tools and instruments that a network wants to allow itself to check its alignment with its goals. Material equipment provides an overview of the financial, organizational and staff resources available to the research network [LNAF04]. Within the StArG meta project, this data has been collected in 19 Transfer-Diagnosis Workshops and a SWOT-Analysis "Funding Structures as Transfer Concept" and has then been clustered into the components Strategy, Culture, Structure, Diagnosis and Leadership and Cooperation. These findings of the research network constituted the decision basis according to which the StArG meta project selected and employed management methods and network services during the course of the funding priority "Preventive Occupational Health and Safety" (see Fig. 2).

When employing the selected methods of network management requirements of research founding and of individual work within the project have to be taken into consideration [Sau05].

Table 2 Exemplary set of qualitative criteria for successful network management

Creation of a common identity	Sub- and joint research project	Joint filing of applications, project conferences
	Focus groups	Regular focus group meetings
	Funding priority	Common logos and templates
Strengthening of shared research interest	Sub- and joint research project	Joint project work and publications
	Focus groups	Scientific discourse on topics of the focus groups
	Funding priority	Joint annual conferences, use of iDA, Workshops for junior scientists
Creation of trust	Sub- and joint research project	Joint project work
	Focus groups	Regular meetings, joint presence at fairs, e.g. the 2nd BMBF Future Forum on Innovative Ability
	Funding priority	Joint fair presence A+A, joint information channels
Common language	Sub- and joint research project	Publications, reports
	Focus groups	Position papers, design of focus group bulletins, strategy planner
	Funding priority	Joint publication in three conference transcripts, compilation of the Aachen Impulse

3.3 Effectiveness of the Research Network Funding Priority Preventive Occupational Health and Safety

As mentioned above, certain funding and transfer structures have been implemented to ameliorate transfer between research and entrepreneurial practice as well as to improve visibility of research on Preventive Occupational Health and Safety in politics and beyond the scope of the funding program. But how can be measured whether, how far and by what means these goals have been attained? As a rule, this assessment can not be based on quantitative factors, instead qualitative “auxiliary constructs” [Klö07] must be factored in, like e.g.

- Formation of a joint identity,
- Strengthening of a shared research interest [RSL04],
- Building of mutual trust between individual members of the funding priority [Geae03] and
- A common language of the funding priority [DdGS06].

The fact that these success criteria have been accomplished through the integrated methods of network management is documented by means of the various products and events that take place on the individual levels of the funding priority (see examples in Table 2).

4 Transfer Engineering – A Concept for Cooperative Research of Academic and Corporate Actors

Today, enterprises and their employees have to cope with fast and constant changes. These changes are characterized by increasing competitive pressure, invariably shorter product and innovation cycles, globalized division of labor and the delocalization of work. Enterprises are thus increasingly exposed to international competition. They have to concentrate all their resources in order to be able to prevail on a globalized market [HHL09].

This innovation pressure as well as the enormous dynamism of the world of work require high flexibility, autonomy and cross-linking, not only of enterprises but also of employees. Additionally, demographic change poses the challenge to enterprises to conserve the employability of their staff for as long as possible. The importance of physical and psychological health of employees has often been underlined as a decisive factor of innovative ability according to the motto, "Only a healthy employee is an innovative employee". In order to safeguard physical and psychological health of employees, work research has long since developed extensive concepts of Preventive Occupational Health and Safety.

But enterprises, too, have identified the health – and thus the capability – of their staff as a decisive factor of productivity and desire to utilize the innovative potential of prevention as an element of a holistic corporate innovation strategy. Currently, a multitude of projects are funded in the scope of the funding priority "Preventive Occupational Health and Safety" that develop practice-oriented solutions for enterprises in the area of prevention. Concerning the implementation of results into the field of practical work, however, the problem of transfer between research and practice does exist.

Interdisciplinarily subsumed under this transfer problem are all factors that lead to insufficient perception and utilization of scientific research results in practice [Hea10]. Results of the StArG meta project point out that transfer issues still remain unsolved in Preventive Occupational Health and Safety. Practitioners complain about a lack of practical relevance in parts of scientific research, researchers criticize the lack of implementation of their findings into entrepreneurial action. The cause often lies in transfer failure.

But what is the meaning of the term "transfer"? [HLBH09] point out that a specification of the term Transfer is necessary. Besides the already mentioned aspect of transfer in breadth, which serves mainly to address and sensitize the stakeholders of the prevention landscape, Transfer in depth is the other issue which mainly takes place on the project level. Transfer in the sense of Transfer in depth refers to cooperative research (mainly on the project level). To this end, concepts of knowledge generation and implementation into action that facilitate cooperative collaboration within actor alliances between scientists, practitioners and intermediaries are necessary.

Doubtless, Preventive Occupational Health and Safety contributes to strengthening innovative ability (especially [HLBH09] but also [HLH]). According to [KK00], innovation can be understood as a constructive learning process that comprises both conceptionalization and utilization. Still, this reciprocity of the innovation process is rarely mirrored in the constellation of its actors. Often, those persons developing innovations are both organizationally and professionally independent of the later users. New products or processes are produced in a research facility to later be transferred, via a multitude of channels, into practice. [HLBH09] suspect the causes for frequent lack of practical relevance of research findings to lie on the one hand in the fundamental divergence between scientific and entrepreneurial goals as well as in part in the insufficient aptitude of practitioners to formulate current demands for research. These symptoms are amplified by the weakness of feedback mechanisms that are intended to supply scientists with practice know-how that could serve to orient their research activities.

Thus, on the one side there is the scientist in his quest for universally valid knowledge and the expansion of his discipline's knowledge base; on the other stands the practitioner who is interested in maximally fast, effective and economic solutions. The different interest horizons, action logics, processing contexts and everyday environments of scientists and practitioners can lead to the fact that research results end up having little relevance for practical work [Sau05].

All this shows that strategic transfer concepts have to be applied not only at the traditional stage of knowledge transfer, but already at the stage of knowledge production [Hea10]. "The problem of knowledge transfer already begins during the phase of knowledge generation" [Lud07]. The field of conflict between the individual system associations and action logics of researchers and practitioners can only be solved through mutual understanding that necessitates an intensive exchange between science and practice.

This implies the renunciation of the sender-receiver notion in "transfer" work [LH09]: Transfer is not about the isolated search for solutions for entrepreneurial practice with a universal claim for implementation. In fact, both the specifics of entrepreneurial necessities and framework conditions and the interest in knowledge of research must be equally taken into account in cooperative project work. In order to allow for this, the area of applied research increasingly opts for cooperative methods when working in collaboration between research and (entrepreneurial) practice. The integration of heterogeneous actors from business, scientific organizations and service providers progressively gains importance [Sau05].

One approach that satisfies the resulting demands for cooperation design between the heterogeneous project participants is Transfer engineering. Transfer engineering describes a concept that incorporates design aspects and methods for a systematic development of communication and collaboration between actors from research, entrepreneurial practice, intermediaries and inter-corporate partners in application-oriented research projects. Dimensions of description and design are being discussed in literature within the scope of studies on participation and empowerment as well as currently on the integration of customers into innovation processes. Information and communication have been identified as crucial influence factors within the innovation process [Bea09]. According to Scholl (2004) [Sch04], one integral cause for failed innovations within research processes are so-called information pathologies between developers and users. These consist of information relevant to the decision process which – while in principle being accessible – is not produced, not transmitted correctly, not obtained or not correctly processed.

Transfer Engineering explicitly deals with all phases of the innovation process and thus with all phases of project work. Collaboration between researchers and practitioners can not be limited to single project phases like e.g. survey phase or utilization phase. Rather, cross-phase influence factors comprise a joint mission and continuous inclusion of all relevant actor groups in order to build a maximum of acceptance [Pay90]. This is especially important if a project is aimed to induce opinion-, attitude- and behavior-relevant change processes on individual or organizational levels, as is the case with most of the projects on Preventive Occupational Health and Safety.

Thus far, when developing products or services in research projects, often only one partners' benefit has been considered: either the scientists' quest for knowledge or the requirements of practice. Against the background of current discourse on Innovation Through Customer Orientation, demands of research funders for more customer orientation of research projects are being voiced: Results of research projects should be accepted and needed, there should be a demand for the findings, and results should be appropriate to the demands of the practitioners. Additionally, "customer orientation", i.e. in this context practice-orientation, is not to be understood as relating only to products of research, but also to the very process of development resp. innovation. Thus, in the style of Bruhn [BH03], beside the criterion of customer orientation resp. practical relevance of a research project's findings the criterion of customer proximity of interactional behavior has to be applied.

But who is actually the customer in a research project? It is necessary to "reflect that not only [...] science intervenes into a system of practice, but that same holds true of the system of practice intervening into science" ([HSS09], own translation). Within the Transfer Engineering concept, we prefer to use the terms "Supplier" and "Consumer" instead of a customer relationship between research and practice. This stresses the exchange process between the actors of project work: Both researchers and practitioners provide certain specific service offers for the respective partner while expecting to profit from specific benefits offered by the respective partner and the joint project work.

As the borders between provider and consumer in a research process become blurred with both entrepreneurial practice and research playing the role of both "customer" and provider, the dimensions of customer orientation stemming from the context of industrial goods [BH03] have to become bi-directional: An application-oriented research project shows customer orientation if the development process and the obtained results

a) are beneficial and useful for (entrepreneurial) practice
b) serve the knowledge interest of research, while at the same time the interactional behavior of the participating parties permits that
c) researchers obtain continuous, transparent insights into entrepreneurial practice, thus making them effectively a part of practice,
d) practitioners are involved into research processes as experts, thus making them effectively a part of research.

Concerning the subject matter of project work contrary interests can be the case. Often the entrepreneurial interests in prevention – if there is an interest at all – are fundamentally different as those of prevention research [HLBH09]. Based on the differing expectations a mutual subject matter on which interaction and cooperation is sought in the research process has to be defined. The actors should coordinate their actions in such a way that a mutual subject matter can be worked on [Dun04] in order to design a cooperative process of providing services. This leads to a changed role of the project actors: The practitioners change away from a passive observed object toward being a co-producer of research findings; researchers in turn change from being observers toward consultants, moderators, tutors and service providers in an application-oriented context.

In order to support this very process, it is desirable to instigate a communication and cooperation developing process between project actors in the sense of Transfer Engineering. Results from the StArG meta project show the transfer-facilitating influence of long-term transfer partnerships between research and practice. Mutual recognition of scientists and practitioners as equally competent experts within project work has proved to be even more decisive than the employment of interactive transfer methods. It is thus advisable to make room for communication and cooperation within a project's work that allow researchers and practitioners to equally apply their expertise to joint development processes in order to create a benefit for both sides [Val09]. The effectiveness and efficiency of project work can be augmented by making complementary areas of expert knowledge available to all project partners as soon as possible. This is why an integration of practice into the knowledge production process (read: research) is recommended to be put into effect already at the application stage, so that the borders between producer and recipient of knowledge – in other words between production and transfer – are lowered in favor of a transfer partnership between equals. Integration is not about making the differences between research and practice "disappear, but to equalize them through understanding- and negotiation-oriented processes aiming at reaching joint decisions acceptable to all parties" [HSS09] (own translation).

5 Conclusion

The integration of the two approaches "Strategic Network Management" and "Transfer Engineering" serves to successfully initiate future research in the thematic field of Occupational Health and Safety. They can help to increase visibility and to make sure that project findings are truly generated in cooperation with entrepreneurial practice. This serves to make results not only available to the active Value Partners but also helps findings gain a broad relevance throughout networks and society. Finally, it lessens the communication gap between science and practice.

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Measuring Intellectual Capital

Sabine Bischoff, Gergana Vladova, Sabina Jeschke

Abstract Steady knowledge production and a great innovative capability are crucial attributes, if not necessary prerequisites, that companies need to be and remain competitive on today's market. The open innovation approach provides an opportunity within this article to increase companies' innovative capability. The article also deals with the question as to how intellectual capital can be measured in the innovation process.

Key words: Intellectual Capital, Open Innovation

1 Introduction

As the knowledge society has developed, there has been a considerable shift over the last 25 years in many sectors of industry in favor of the knowledge production factor. As early as the year 2000, the proportion of this production factor in total corporate added value was 60 % on average [e.V00]. A great innovative capability and the successful generation of innovation essentially holds the key to sustainable corporate success and positive growth, even for the *SME stimulus for innovation*. In the light of these facts, the demand for more information about the knowledge production factor on the part of many boards of management is understandable. In addition, intangible factors, including the knowledge production factor, increasingly play a major role in business valuations (i.e. from the shareholder's point of view). Even when the market value of the so-called intangible assets exceeds that of the

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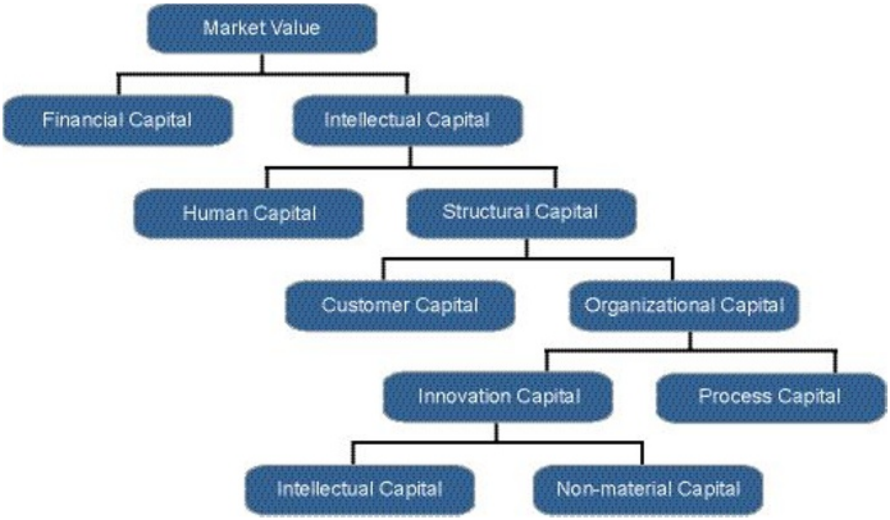

Fig. 1 Categorizing intellectual capital according to Edvinsson and Brünig [EB00]

book value [Hel01], balance sheets these days also show almost exclusively tangible assets. Interim reports are increasingly obligatory, for instance as stipulated by the regulations of the International Accounting Standard (IAS) and the International Financial Reporting Standard (IFRS).

The terms intangible assets, intellectual capital, knowledge capital and intangible assets are used interchangeably in many cases in literature as well as in business practice. The term intellectual capital is used below as a result of the BMBF International Monitoring Project focusing on the central theme of *Enabling Innovation* and the core area of "human potential as an innovative and competitive advantage" (translated by author).

Against the background described above, this article deals with the classification and valuation of intellectual capital and with the clarification of the significance of relationship capital as part of the same. This is demonstrated in the example of the open innovation concept.

2 Classification of Intellectual Capital

Edvinsson and Brünig [EB00] differentiate between financial capital and intellectual capital, which together account for a company's market value, see Fig. 1. While financial capital is being formed from the company's tangible and fixed assets, the intellectual capital is being specified. Edvinsson and Brünig then differentiate further between human and structural capital. In their opinion, human capital is based on experience, skills and knowledge. In contrast, structural capital consists for its

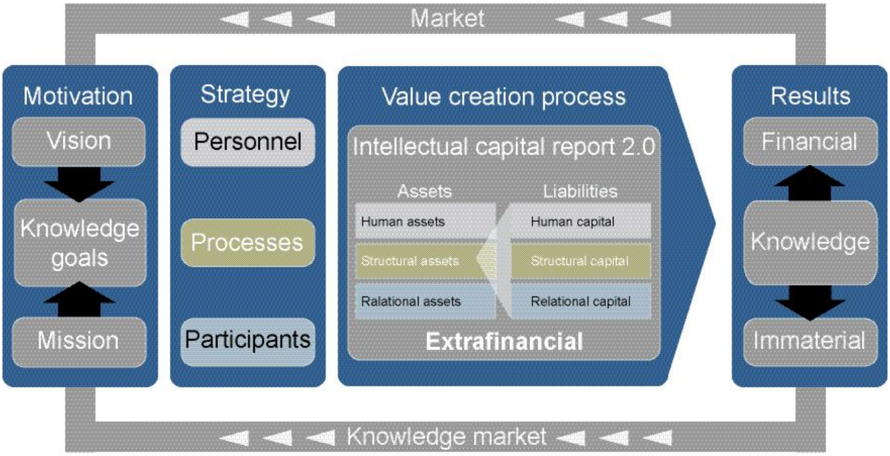

Fig. 2 Intellectual capital report 2.0 [KLB00]

part of customer capital (characterized by the customer base, customer relations and customer potential) and organizational capital. The latter differentiates again between innovation capital and process capital.

Another widespread classification in German-speaking areas is one that differentiates between human, structural and relationship capital. Koch and Schneider developed this new structure in 1998 and thus presented the first concept for a so called “financial knowledge report”. The Austrian Research Centre Seibersdorf applied the new concept in 1999 which today still consists of the first ideas [KLB00]. In 2007, Koch and Leitner refined the concept and developed an economic oriented concept of the knowledge report. It was publicized in 2008 [KL08].

3 Measuring and Evaluating Intellectual Capital

The company’s innovative capability does not just depend on the knowledge and potential of individuals, but specifically on their interdisciplinary and interactive thinking and action. The prerequisite for emerging innovation is embedded in networks and is initially derived from the relationship and/ or interaction between the individuals [LA]. The potential and innovative capability can therefore be found in “knowledge resource networks” [LC99] and may produce innovations, depending on the quality of the relationships between the individual intersections of a network. Innovation in this sense can be understood as the effect of synergy in the relationship of separate individuals. In order to be able measure and evaluate the innovative capability within an organization [BAF10], there is, however, a lack of academically funded models that examine and describe the individual’s intellectual capital. Appropriate evaluation procedures therefore need to be developed, which describe and objectively evaluate intellectual capital so that it can be recorded as company assets as part of the relationship capital. Consequently, no conclusion is yet possible about a company's innovative capability.

Existing procedures for including important intangible results such as, for example, the balanced scorecard [KN96], are not specific enough in view of their generic nature to serve as an adequately funded model. There are many other approaches and methods, however, for evaluating working knowledge [Sve01].

The best known method is the "Skandia Navigator" [EM97] of the Swedish insurance and finance group, Skandia. By the middle of the 1990s, they had already begun publishing intangible assets in so-called interim reports. The output of this method is the *Intellectual Capital Report*. This is a report on operational intellectual capital in addition to the annual report. The value of intellectual capital is determined by the so-called Skandia Market Value Scheme, which places the market value within a hierarchical structure.

Another method is the "intangible asset monitor" [SH02]. This is a system based on the knowledge organization for measuring the intangible asset. As a non-financial scorecard system, the intangible asset monitor should be regarded as an additional demonstration of a company's financial success and its shareholder value.

Sveiby sums this up as follows:

> No one method can fulfill all purposes; One [...] must select methods depending on purpose, situation and audience [Sve01].

4 Processes of Innovation and Open Innovation

Having demonstrated how intellectual capital can be classified and how important it is for a company to measure intangible assets, a relatively recent theoretical concept will be discussed here, based on the example of open innovation, with the aim of showing the importance of a company's external relationships for its innovative capability and also, therefore, for its success.

Increasing the efficiency of product development and companies' own innovative capability has always been an important prerequisite for success. By utilizing ideas and technologies in innovations, companies are able to tap new markets and maintain their competitiveness. Whereas large enterprises have the necessary financial and human resources to carry out their own research and development projects, meager resources and limited know-how characterize small and medium-sized enterprises (SMEs). It therefore proves difficult for them to find new ways and tackle challenges created by changing market conditions on the one hand and the realignment of large enterprises on the other hand [BDH+07]. In this context, companies and SMEs are particularly dependent on the involvement of external resources and know-how for increasing their innovative capability and therefore their competitiveness in cross-linked cooperation.

Potential groups of external partners in the innovation process, according to von Hippel (1987), are:

1. Customers and suppliers
2. Universities, public institutions
3. Competitors and
4. Other nations.

In the context of knowledge management, Sveiby concedes that external players have a significant role in a company and refers to the acquisition of new knowledge as "intangible income" [Sve98](translated by author). It is important for companies that know their own customers well to be able to offer the best solutions. Satisfied customers also have a positive impact on image-building because companies are able to refer to them. However, the opportunity to use and integrate the knowledge and experience of customers as well as business partners (suppliers, for example) into the company's own process of innovation is particularly important. In the search for appropriate solutions, the company is able to use external know-how for the purposes of improving profits and growth [Sve98, vH87].

The *open innovation approach* provides companies with new opportunities for structuring external relationships and the flow of knowledge, but also sets new challenges for innovation management [VDJvdVdR08]. In the past, companies preferred to use internal research and development (R&D) and innovation resources for developing and marketing new products, and did not really involve the external environment [Che03, GB06]. A wide variety of factors, such as globalization, new market participants, shorter product life cycles, smaller R&D budgets and rising R&D costs superseded this *closed innovation* strategy at the end of the last century [GE06, GR99]. Chesbrough coined the term *open innovation* as a response to the new challenges. External resources in the innovation process were accorded a significantly greater importance in this approach than was the case in the closed innovation strategy.

The new innovation strategy is defined by Chesbrough 2003 as follows:

> Open Innovation is a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology [Che03].

Chesbrough extended this definition in 2006 as follows:

> [...] open innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively [Che].

A comprehensive *open innovation strategy* offers companies many opportunities, but also poses new challenges. The knowledge-intensive innovation processes must to some extent be reorganized to include external players and the knowledge gained to be transferred to the organizational knowledge base.

The significance of the informal transfer of knowledge and informal relationships with external cooperating partners, customers, suppliers and even competitors within the open innovation process and the development of an appropriate internal knowledge base should be emphasized here [Che, vH87]. These relationships that are difficult to grasp and formalize have a decisive influence on the success of the innovation phase, even at the stage where ideas are being generated [Con95]. Nor should the significance of relationships among internal experts be underestimated. Informal relationships, however, are unstructured and, if anything, transparent [Por08, Str10]. The nature of knowledge disseminated by socialization is usually implied and remains in the individual knowledge base of those employees who are directly involved [Por08, Epp07, NT95, EE07]. SMEs are faced with the challenge in their innovation processes of evaluating relationships and knowledge and structuring the processes of associated organizational learning [CL90]. The identification of experts and the exchange between them in particular must be guaranteed in order to improve the progress of the innovation process [Epp07, EE07] and to establish how the company can successfully integrate internal and external sources of knowledge [BH02].

In summary, it can be said that the exploration and inclusion of external experiences and knowledge and the organization of an external network is usually a natural continuation of well-structured, consistent innovation management deep-seated within the company. The strategic opening of the innovation process is only sensible and advisable if the company's in-house structures are prepared for it. Functioning innovation management creates the framework in which it is possible to make the best possible use of external resources. Structured management of knowledge that incorporates the three levels of *technology, organization* and *human resources* in equal measure is essential for managing complex innovation processes and becomes particularly important when companies cooperate with external bodies [VM10].

The focus in innovation management by companies is increasingly changing against the background of these developments. Incorporation of the external environment increasingly needs to become an integral part of the entire innovation management concept. New opportunities then arise for medium-sized enterprises for strengthening their innovative capability and long-term competitive position. In order to make use of these opportunities, companies need to control, speed up and optimally plan their own (open) innovation process using a variety of methods. Similarly, individual core skills should therefore be enhanced and concepts developed for protecting intellectual property.

5 Summary

This article has demonstrated that the knowledge production factor has clearly grown in significance over the last ten years, both for large enterprises as well as for SMEs. Business valuations increasingly frequently include intangible factors as well. The term *intellectual capital* emerged in this connection. This intellectual capital combines a company's structural capital, human capital and/ or relationship capital. These items are combined in what are referred to as intellectual capital reports and their asset and liability values issued.

Companies continue to be challenged by limited internal resources, particularly financial and human resources, in their innovative capability. Limited know-how is, of course, also associated with this. The closed innovation paradigm, which has been predominant to date, has been discouraged by including external players in the process of innovation. The innovative *open innovation approach* makes it possible for companies to supplement their internal ideas with external ones and to increase the innovative capability with this additional knowledge potential. No limits have been set on the possibility of including external ideas, whether these involve customers, suppliers, competitors, academics or other institutions. It is important in this context to create appropriate structures in the company for exchanging knowledge in both directions. This integrated concept of innovation management strengthens the competitive position of companies and, in so doing, their chances of operating successfully on the market.

The question arises in this context as to how recently acquired knowledge, the intellectual capital, is measured. Two concepts were briefly envisaged here with the Skandia Navigator and the Intangible Asset Monitor. Which method will ultimately be applied in the company remains unresolved due to the specific situation of the company at the time. Indeed, the thinking here shows that in future, the processes of generating and transferring knowledge and therefore of measuring and evaluating it, will increasingly be the focal point.

6 Future Research Requirements

Future research requirements can be deduced from the current gaps in research in the area of measuring intellectual capital. They therefore also lie in the development of structures for supporting the transfer of knowledge between employees. In addition, it is still not possible at present to visualize informal internal and external relationships so that the knowledge *tucked away* there can similarly be externalized without loss.

To this end, the open innovation conceptual model needs to be synchronized with existing theories of knowledge management in future research work. Innovation processes are knowledge-intensive processes, in which the transfer of knowledge must be controlled within them in a target-oriented manner. Existing knowledge management theories should also expanded for this purpose with innovation-specific attributes. Based on the importance of informal networking in (open) innovation processes, there is both a fundamental as well as an application-oriented research requirement on this subject [VA09].

A further problem in this regard is that of the protection of *private property*, because the involvement of external players in the innovation process is not absolutely safe for the independent company. By indicating the intangible assets, i.e. knowledge, in interim reports or the year-end accounts themselves, know-how is disclosed and therefore possible core skills made accessible to anybody. This disclosure is a major obstacle for companies and employees who do not want to see their work valued in order to protect their own reputation.

In this regard, companies need to some extent to practice knowledge management *the other way round*. Instead of merely pursuing the usual goals of knowledge dissemination for knowledge management, the framework conditions should be adjusted, for example extensions and adaptations of the theoretical approaches towards the protection of intellectual property. These specifically concern the company's internal situations and protective measures used to prevent inflows and outflows of information and knowledge in order to protect itself from knowledge unintentionally draining away (cf. Bahrs et al. 2010). In practical terms, this means banning USB sticks, for example, or other storage media. It is also possible to implement cloud computing here. This involves an approach which makes IT infrastructures (e.g. calculating capacity, data memory, etc.) available over a network and therefore removes them from the company. Professional secrecy clauses and confidentiality agreements have long been an integral part of today's contracts.

7 Outlook

On the basis of what has been outlined so far for Germany as a knowledge center, fundamental approaches like corporate knowledge – the intellectual capital – can be externalized. The designation of so-called intellectual capital reports or the Skandia Navigator approach (interim reports on the annual return) are preliminary steps towards an integrated business valuation.

Changes are also needed on a micro-economic scale. From the buzzword open innovation, relevant recommendations for action need to be drawn up in future for corporate practice – and particularly SME practice, in order to remain competitive in an increasingly globalized world.

At the macro-economic level, from a national economic viewpoint, an investigation should be carried out, for example, into to whether certain industries, which tend to operate stronger open innovation, are more successful on the market.

In political terms, the question then arises as to the improvement in legal and economic framework conditions in relation to open innovation in different industries. Finally, both companies and other branches of the economy still not operating open innovation at present should be empowered to apply open innovation by appropriate regulations and laws.

When organizing external political and economic framework conditions for open innovation in companies in the future, the focus here should be on the following areas [DJVKC08]:

- Networks and collaboration as a starting point for cooperation with competent partners.
- Support when setting up firms – an example of this is spin-offs as a source for targeted exchange of knowledge and close profiling.

- IP management as a source of new ideas and opportunities for marketing the company's own know-how.
- Research and development work in the company with the aim of promoting the uninterrupted development and expansion of the company's own knowledge as well as the cooperation of companies and research institutions.
- Well-trained staff with many opportunities for on-the-job-training.
- Adequate funding opportunities for companies operating open innovation.

The focus should not be on certain firms or sectors of industry when implementing appropriate political and economic measures. Rather, the success of these measures depends on looking at open innovation as a change in paradigms and system.

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Agile Prozessgestaltung und Erfolgsfaktoren im Produktionsanlauf als komplexer Prozess

Esther Borowski, Klaus Henning

Zusammenfassung Eine agile Vorgehensweise, die sich nicht nur auf den Softwareentwicklungsprozess bezieht, sondern ebenso auf das Management des Produktionsanlaufs, kann in einem zeitkritischen komplexen Entwicklungsprojekt erfolgreich angewendet werden. Dabei bedeutet dies für alle Akteure die Grundwerte und -prinzipien des agilen Manifestes praxisnah umzusetzen und die gesamte Managementstruktur nach dem Dynaxityprinzip für turbulente Prozesse mit hoher Struktur- und Prozesskomplexität sowie einer Orientierung an den Erfolgsfaktoren für komplexe Prozesse ausgelegt werden. Beide Vorgehensweisen stammen aus unterschiedlichen Akteursgruppen in Wissenschaft und Praxis. Das Fallbeispiel zeigt, dass sie sich erfolgreich miteinander verknüpfen lassen. Turbulenztaugliches Systemisches Management und Agile Softwareentwicklung können so zu einem Gesamtvorgehensmodell zusammengeführt werden, das zum Management des Produktionsanlaufs eingesetzt werden kann.

Schlüsselwörter: Komplexe Produkte, Agiles Vorgehensmodell, Produktionsanlauf

1 Einführung

Zahlreiche Produkte sowie tägliche Innovationen und Technologien haben insbesondere in der jüngsten Vergangenheit zu einer immensen Steigerung der Angebots- und Variantenvielfalt geführt. Mit diesem Trend gehen eine Verkürzung der Entwicklungszeit und eine beschleunigte Markteinführung einher. Das Resultat dieser Produktoffensiven ist eine steigende Anzahl von Produktanläufen mit exponentiell steigenden Variantenverhältnissen, die es in Unternehmen und Arbeitspro-

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zesse zu integrieren gilt (vgl. [HBH04], 2004, S. 2). Die Beherrschung von Produktionsanläufen unter diesen veränderten Umweltbedingungen bereitet Probleme, wie beispielsweise eine erhöhte Prozesskomplexität, Prozessparallelisierung und -integration sowie eine Zunahme von Schnittstellen [Wil07].

Die Fähigkeit, komplexe Produkte im vorgegebenen Qualitäts-, Zeit- und Kostenrahmen einzuführen, wird zukünftig zu einem entscheidenden Faktor der Wettbewerbsfähigkeit [NNT08]. Hauptaufgabe ist dabei nicht mehr die Aneinanderreihung der Entwicklungs- und Planungsschritte, sondern vielmehr die Beherrschung der Komplexität des Anlaufmanagements, das unzählige parallele Einzelschritte unterschiedlichster Disziplinen und Partner zusammenführen muss [SSS08]. Nach einer Einführung in die Thematik des Produktionsanlaufs und seiner Schlüsselposition im Produktionsprozeß wird insbesondere die Komplexität im Produktionsanlauf adressiert. Hierbei werden die Komplexitätstreiber beleuchtet und diese im Hinblick auf das Anlaufmanagement als komplexer Prozess reflektiert. Im Anschluss wird zunächst Agilität, als Fähigkeit mit zunehmender Komplexität umgehen zu können, vorgestellt und anhand eines Praxisbeispiels Erfolgsfaktoren zum Management komplexer Projekte aufgezeigt. Die Anwendung einer Kombination der Prinzipien der agilen Prozessgestaltung und der Erfolgsfaktoren und somit Gestaltung des Managements des Produktionsanlaufs wird in einem weiteren Anwendungsbeispiel aus der Praxis vorgestellt.

2 Anlauf – Schlüsselstelle im Produktentstehungsprozess

Der Anlauf lässt sich innerhalb der Phase der Produktentstehung als entscheidende Schlüsselstelle identifizieren. Das primäre Ziel der Serienanlaufphase besteht darin, ein neues Produkt aus den Laborbedingungen der Entwicklung sukzessive in ein stabil produzierbares Serienprodukt zu transferieren [CF91] (vgl. [Pis91, Bis07]). Dabei wird der Produktionsprozess so gesteigert, dass er sich von einer Einzelfertigung zur Serienproduktion entwickelt [TBC01]. Beendet wird der Anlauf durch Erreichen der Kammlinie, die als eine vom Unternehmen festgelegte Outputhöhe definiert werden kann. Die Autoren Risse [Ris03], Kuhn [KWES02], Housein [HW02], Winkler [WS08] und Voigt [VT05] teilen diese Sichtweise des Anlaufs und verwenden ähnliche bzw. identische Definitionen. Der Anlauf beinhaltet die Phasen Vorserie, Nullserie und Produktionshochlauf. Die Phase vor dem Anlauf wird als Serienentwicklung bezeichnet, die nach dem Anlauf als Serienproduktion. [SSS08]

Das Management des Anlaufs wird von Kuhn folgendermaßen definiert: „Das Anlaufmanagement eines Serienproduktes umfasst alle Tätigkeiten und Maßnahmen zur Planung, Steuerung und Durchführung des Anlaufes, ab der Freigabe der Vorserie bis zum Erreichen der geplanten Produktionsmenge mit den dazugehörigen Produktionssystemen unter Einbeziehung vor- und nachgelagerter Prozesse im Sinne einer messbaren Eignung der Produkt- und Prozessreife“ [KWES02] (vgl. Abb. 1). Diese allgemeine Definition beschreibt die Problematik des Anlaufmanagements. Es wird von „allen Tätigkeiten“ gesprochen ohne explizit eine zeitliche

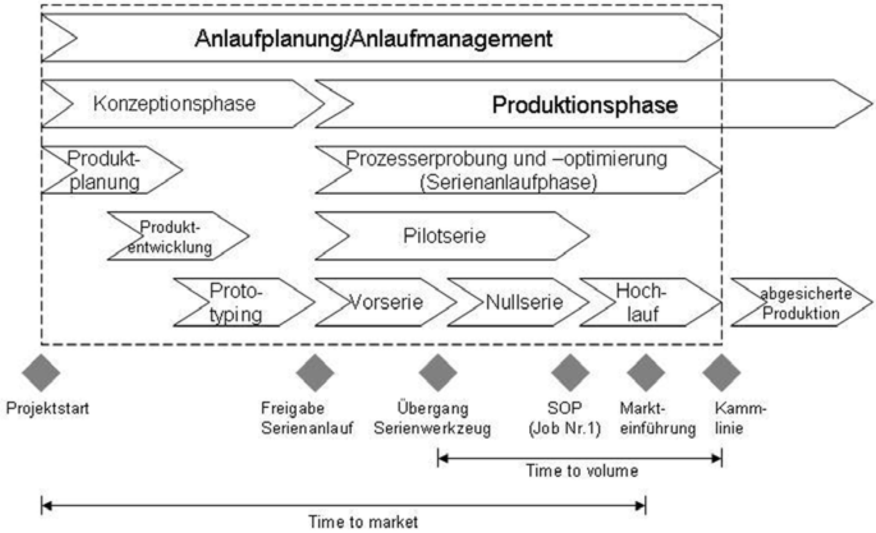

Abb. 1 Anlaufmanagement im Produktenstehungsprozess (In Anlehnung an: [Bis07, Ris03, Fit06, vW98])

Komponente zu nennen. Aber besonders die Festlegung des Beginns des Anlaufmanagements sowie seine Tätigkeiten sind besonders diskutierte Punkte.

Romberg bezieht die zeitliche Dimension in seiner Definition mit ein. Er beschreibt das Anlaufmanagement als einen interdisziplinären Geschäftsprozess, der alle Vorgänge von der Planung bis zur Serienfertigung umfasst [RH05]. Aus diesen zwei Definitionen wird ersichtlich, dass der Beginn des Anlaufmanagements nicht eindeutig definiert ist und die Autoren den zeitlichen Umfang des Anlaufmanagements unterschiedlich festlegen. Jedoch steht in allen Betrachtungen und Berichten aus der industriellen Praxis die Fokussierung auf der Begegnung der Komplexität des Anlaufmanagements, das unzählige parallele Einzelschritte unterschiedlichster Disziplinen und Partner zusammenführen muss, im Vordergrund [SSS08].

3 Komplexität im Anlauf

Selbst in wissenschaftlicher Literatur ist heutzutage der Begriff der „Komplexität“ bzw. die Feststellung ein „Sachverhalt sei komplex“ zur modischen Einleitung der Arbeiten geworden. Leider werden diese Sachverhalte häufig nicht unter Einbezug ihrer vollen Komplexität untersucht, häufig wird die Komplexität zur Rechtfertigung des Gebrauchs reduktionistischer Forschungsstrategien genutzt. Eine gewisse Ohnmacht gegenüber dem Phänomen „Komplexität“ zeigt sich durch den Gebrauch des

Begriffes in einem umgangssprachlichen Sinne von kompliziert, undurchschaubar oder unverständlich, dessen Gebrauch prinzipiell richtig ist.

Betrachtet man die „Komplexität“ als wissenschaftliches Problem, kann man sich ihr von einer analytisch-reduktionistischen Seite nähern, oder den nachfolgend gewählten systemisch-interaktionistischen Ansatz nutzen. Unter Komplexität wird die Eigenschaft von Systemen in einer gegebenen Zeitspanne eine große Anzahl von verschiedenen Zuständen annehmen zu können verstanden. Dieser Charakter erschwert die geistige Erfassung und Beherrschung durch den Menschen. Daraus ergeben sich vielfältige, wenig voraussagbare, ungewisse Verhaltensmöglichkeiten [Ble].

Zur Quantifizierung der Komplexität bietet sich an die Maßeinheit Varietät zu nutzen. Varietät ist die Anzahl möglicher Zustände eines Systems. Die Zunahme der Varietät ist durch die Globalisierung und die verbesserten Informationstechnologien deutlich angestiegen. Dem gegenüber steht die Abnahme der Halbwertzeit von Wissen. Die Varietät im Umfeld von Organisationen hat heute deutlich gegenüber der Vergangenheit zugenommen. Hinzu kommt, dass in Zukunft mit einer Verstärkung dieses Prozesses zu rechnen ist.

Eng verbunden mit dem Begriff Komplexität ist der Begriff Dynamik. Die Dynamik betrachtet nicht die Anzahl der verschiedenen Zustände eines Systems, sondern die Zeit, die benötigt wird, von einem Zustand in einen anderen zu wechseln. Diese Eigendynamik zeichnet sich dadurch aus, dass sich die Elemente und deren Beziehungen zueinander im Zeitablauf ändern [Kre07].

Durch die bereits beschriebenen äußeren Umstände, beispielsweise der zunehmenden Globalisierung haben die Veränderungsgeschwindigkeiten von Zuständen deutlich zugenommen. Diese Entwicklung fordert eine entsprechende Lerngeschwindigkeit in Organisationen, sowie ein verbessertes Imaginationsvermögen. Der Anteil an unscharfem Wissen steigt dramatisch und damit auch die Notwendigkeit der Fertigkeiten, mit diesem so genannten Fuzzy-Wissen umzugehen.

Wenn wir nun davon ausgehen, dass die Stärke von Komplexität und Dynamik das Umfeld von Organisationen prägen, ist der Bedarf an organisationaler Intelligenz besonders hoch, wenn Dynamik und Komplexität hoch sind. Es ergibt sich das Phänomen der Zeitschere, bei steigender Komplexität nimmt der Bedarf an Entscheidungs- und Handlungszeit zu, jedoch die verfügbare Entscheidungs- und Handlungszeit nimmt bei steigender Dynamik ab.

Rieckmann umschreibt die sich gegenseitig intensivierenden Wechselwirkungen von wachsender Dynamik und zunehmender Komplexität bei steigender Macht/Ohnmacht/Risiko-Relation auch als „Dynaxity“ [Rie00].

Die so genannte Dynaxity, ein Kunstwort, dass sich aus den Begriffen „dynamics“ (Dynamik) und „complexity“ (Komplexität) zusammensetzt, wird in der Abb. 2 grafisch dargestellt [Rie00].

Vor diesem Hintergrund ergibt sich folgende Kernfrage für das Management solcher komplexdynamischen Zusammenhänge: „Wie kann die Handlungsfähigkeit [. . .] von Individuen, Institutionen, Organisationen und Unternehmen unter wechselnden Zielen, turbulenter werdenden Umfeldbedingungen, bei wachsender Kom-

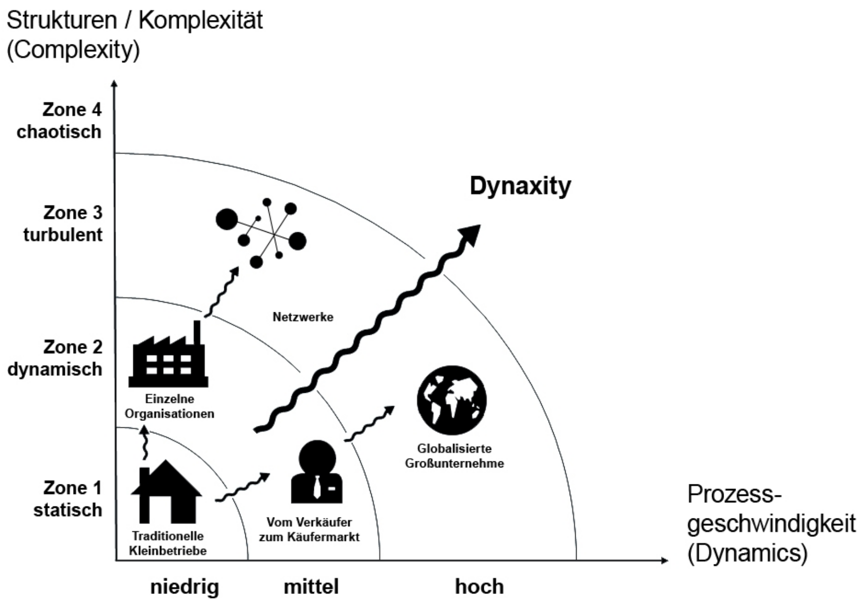

Abb. 2 Darstellung von Dynaxity [Hen99]

plexität, prinzipiell unvollständigen Informationen sowie schrumpfenden Planungshorizonten noch sichergestellt werden?" [HI98].

Die Komplexität im Produktionsanlauf ist neben der Komplexität der Umwelt und somit des Produktes zum Einen auf die Vielzahl interdependenter Gestaltungsobjekte (wie Technologien, Produkt, Prozesse, Produktionssystem, Personal, Logistikkette) und Disziplinen (insbesondere Produktentwicklung, Produktion, Logistik, Einkauf) und zum Anderen auf die dynamischen Zustandsveränderungen der Gestaltungsobjekte und Disziplinen zurück zu führen.

Die Gestaltungsobjekte werden während des Produktionsanlaufs erstmalig in Beziehung gesetzt und versetzt, so dass sich daraus resultierende Wechselwirkungen erst im Anlauf zeigen. Diese durch eine Vielzahl von Schnittstellen geprägte organisatorische Komplexität ist charakteristisches Merkmal der Anlaufphase. Zur Vermeidung und Reduzierung der hieraus entstehenden Ineffizienzen in der Anlaufphase besteht die Herausforderung aus organisatorischer Perspektive, diese Vielzahl von Schnittstellen in den Teilprozessen des Anlaufes zu definieren, zu analysieren und zielorientiert zu gestalten.

Zur Bewältigung dieses komplexen Prozesses „Produktanlauf" müssen zahlreiche Schnittstellen integriert werden. Die aufgezeigten Schnittstellen (vgl. Abb. 3) lassen sich grundsätzlich in produktbezogene und organisatorische Schnittstellen unterscheiden.

Es kann ein enger Zusammenhang zwischen den organisatorischen und technischen Schnittstellen identifiziert werden, da durch die gemeinsame arbeitsteilige

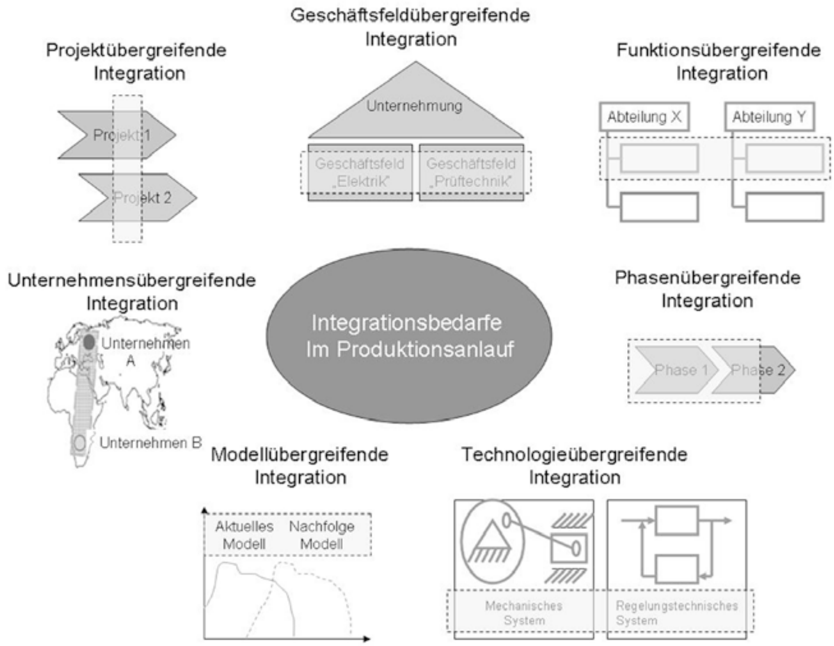

Abb. 3 Integrationsbedarfe im Produktionsanlauf. [vW98]

Entwicklung eines neuen Produkts und der dazugehörigen Prozesse sich der Harmonisierungsbedarf an einer bestimmten organisatorischen Schnittstelle zumeist auch auf eine produktbezogene Schnittstelle bezieht [Jah91]. Obwohl der Harmonisierungsbedarf bereits in der Phase der Entwicklung besteht, zeigt sich eine Vernachlässigung erst während des Produktionsanlaufs bei der Integration der einzelnen produktbezogenen Einheiten bzw. der Integration der Ergebnisse der in den einzelnen Organisationseinheiten bearbeiteten Entwicklungsaufgaben [Vin89].

Beim Übergang von der Entwicklung zum Produktionsanlauf und somit einer Überlappung der einzelnen Phasen im Prozess ist eine Abstimmung zu den Meilensteinen nicht mehr ausreichend, es wird eine kontinuierliche Abstimmung nötig [SR91].

Ergebnisse der Arbeiten von Lawrence und Lorsch konnten die Problematik der Schnittstellen zwischen den Unternehmensfunktionen in Entwicklung und Serienanlauf aufzeigen. Die Funktionen arbeiten hier in einem von umfangreichen und häufigen Situationsänderungen geprägten Umfeld zusammen. Beide Funktionsbereiche Entwicklung und Produktion, deren enge Zusammenarbeit insbesondere im Produktionsanlauf notwendig ist, werden bereits von Lawrence und Lorsch als Referenzbeispiel für eine hohe Divergenz zwischen Organisationseinheiten angeführt. Ähnlich divergierende Einheiten können in den am Produktionsanlauf beteiligten Geschäftsfeldern identifiziert werden.

Der Arbeitskreis „Integrationsmanagement für neue Produkte“ der Schmalenbach-Gesellschaft konnte einen wesentlichen Integrationsbedarf an den Schnittstellen zwischen Entwicklungspartnern ausmachen. Diese Schnittstellen entstehen durch die Fremdvergabe von Entwicklungsumfängen an Zulieferer bzw. durch die gemeinsame Durchführung von Teilprojekten mit Entwicklungspartnern [Rei92].

Die zunehmende Verkürzung der Entwicklungszeiten und der steigende Wettbewerbsdruck in vielen Branchen zwingen zu einer Rationalisierung der Produkt- und Prozessentwicklung. Eine Auswirkung ist die Bemühung nicht sämtliche Produkt- und Prozessmerkmale völlig neu zu erschaffen. Durch das Ausnutzen von Gemeinsamkeiten zwischen Produktgenerationen und Produkten innerhalb einer Produktfamilie sowie durch die Konzentration auf innovative und differenzierende Aspekte soll dem Zeit- und Kostendruck in der Produkt- und Prozessentwicklung begegnet werden [Lie92].

Zur Integration auf den zuvor beschriebenen Feldern ist hoch qualifiziertes Personal erforderlich, welches in der dafür notwendigen Anzahl aber selten verfügbar ist. Zur Bewältigung dieses Dilemmas werden oft weitere personelle Ressourcen in die Produktionsanlaufaktivitäten involviert, wodurch die Anzahl an Schnittstellen und demzufolge auch an Reibungsverlusten wiederum zunimmt [SKF05].

Vor allem dem Charakter der Interdisziplinarität kommt im Hinblick auf die Komplexität hohe Bedeutung zu, da sich das Projektteam im Anlaufprozess aus einer Vielzahl von Personen aus unterschiedlichen Abteilungen und Bereichen des Unternehmens (wie Entwicklung, Produktion, Logistik usw.) zusammensetzt. Hinzu kommen viele Beteiligte anderer Unternehmen, wie Zulieferer, Ausrüster und externe Planer oder Berater. Entscheidend für einen reibungslosen Ablauf sind somit oft die Beziehungsstrukturen der Mitarbeiter untereinander [HLW02]. Diese müssen in komplexen Strukturen des Produktionsanlaufs eng zusammenarbeiten, haben jedoch häufig unterschiedliche Zielsetzungen, aufgrund ihrer unterschiedlichen Abteilungs-, Bereichs-, Werks- sowie Unternehmenszugehörigkeit. Das „Denken in alten Strukturen“ ist weiterhin sehr ausgeprägt, so dass die eigentlich primäre Zielsetzung eines schnellen, wirtschaftlichen und qualitativ hochwertigen Anlaufes von den individuellen Zielen einzelner Bereiche oder Abteilungen, beziehungsweise die persönliche Zielen einzelner Mitarbeiter, in den Hintergrund gedrängt werden. Weiter verstärkt wird diese Problematik, dadurch dass Personen unterschiedlicher Berufsgruppen grundsätzlich unterschiedlichen Denkmustern unterliegen. Das wirkt sich direkt auf die zwischenmenschliche Kommunikation im Projektteam aus. Eine einheitliche gemeinsame Sprache ist nicht vorhanden und kann als Hemmnis für eine adäquate Wissensweitergabe gesehen werden. Weitere Probleme sind in der unterschiedlichen Motivation, Erfahrung und Kompetenz der Teammitglieder, deren Auswirkungen besonders stark unter hohem Zeit- und Erfolgsdruck während des Anlaufs, zu finden. Insbesondere sind in vielen Unternehmen, Teammitglieder im Anlauf gezwungen, die Aufgaben des Anlaufes neben ihrem Tagesgeschäft zu erfüllen. Die parallele Bearbeitung mehrerer, teilweise konkurrierender Aufgaben stellt den Regelfall dar. Die dadurch resultierte Überforderung ruft zwangsläufig bei den Mitarbeitern Frustration hervor, die wiederum zu sinkender Motivation führt. Hieraus folgen die Problematik, dass notwendige Entscheidungen nicht rechtzeitig getroffen werden, so dass zeitliche Verzögerungen folgen sowie die Wahrscheinlichkeit von Fehlentscheidungen [HLW02].

Trotz dieser Hemmnisse und Herausforderungen, die die Interdisziplinarität im Produktionsanlauf mit sich bringt, lässt sich gerade eine interdisziplinäre Zusammenarbeit als Erfolgsfaktor in Innovationsprojekten identifizieren.

4 Interdisziplinarität als Gestaltungselement im Produktionsanlauf

Durch die Ausdifferenzierung unterschiedlicher Wissenschaftsströme und ihre Definition als eigenständigen, sich abgrenzenden Bereich entstanden historisch einzelne wissenschaftliche Disziplinen. Diese bilden sich um einzelne Gegenstandsbereiche und Problemstellungen und spezialisieren sich auf bestimmte theorierelevante Eigenschaften der Realität [Sti94]. Die Identität einer Disziplin resultiert neben den gemeinsamen Forschungsgegenständen und -zwecken aus einem relativ homogenen Kommunikationszusammenhang von Forscher/-innen, einem Korpus an Wissen, Forschungsproblemen, einem Satz von Methoden, Vorgehensweisen und Problemlösungen und einer spezifischen Karrierestruktur [DDG98]. In diesem Sinne lässt sich von Disziplinen als „Subkulturen" sprechen und ihre Fachsprache, Methoden und Theorien als Ausdruck einer disziplinenspezifischen Strukturierung der Realität und damit verbunden einer disziplinenspezifischen Weltsicht identifizieren. Somit ergeben sich unterschiedliche Wahrnehmungsperspektiven und dementsprechend eine spezifische Reduktion der Komplexität.

Der Begriff der Interdisziplinarität wird in der Literatur sehr heterogen verwendet, es ist daher in diesem Kontext sinnvoll eine offene Umschreibung des Begriffs zu verwenden. Interdisziplinarität wird hier in Anlehnung an Defilia, Di Guilio und Scheuermann als integrationsorientiertes Zusammenwirken von Personen aus mindestens zwei Disziplinen mit Blick auf gemeinsame Ziele und Ergebnisse verstanden [DGS05]. Dies meint eine Zusammenarbeit in einem Team aus Personen aus anderen Disziplinen im Hinblick auf gemeinsam festgelegte Ziele unter dem Anspruch auf Konsens, Synthese und Diffusion [DDG98]. Die interdisziplinäre Bearbeitung von Projekten ermöglicht, komplexe Probleme umfassend zu betrachten, erschließt neue Perspektiven und schafft eine Erhöhung des Mehrwerts jeder Disziplin zum Output.

Gerade im Bereich des Innovations- und Anlaufmanagements zeigt sich das effiziente Teamarbeit als entscheidender Faktor im Produktentwicklungsprozess gilt [JS90] und einen notwendigen Beitrag zur erfolgreichen Implementierung von Projekten mit hohem Innovationsgrad liefert. Gerade bei Entwicklungsprojekten und ihrem Anlauf sowie der damit verbundenen technischen Neuartigkeit und Komplexität ist Zusammenarbeit im Team in Bezug auf die Bündelung der unterschiedlichen Kompetenzen entscheidend [He03]. Also hat insbesondere die erfolgreiche Zusammenarbeit von interdisziplinären Teams einen wesentlichen Einfluss auf das Ergebnis eines innovativen Produktentwicklungsprozess.

Insbesondere erfolgreiche Teams in der Produktentwicklung bestehen aus Personen unterschiedlicher Fachrichtungen und mit unterschiedlichem Hintergrund [PP90, SP97]. In der Produktentwicklung lässt sich die interdisziplinäre Zusammensetzung bewusst als Instrument einsetzten, um organisationale Schnittstellen zu überbrücken, da diese Teams die interdisziplinäre Kommunikation und Kooperation stärken [Ern02]. Grundlegend ist in diesem Zusammenhang die Schaffung von Vertrauen und gegenseitige Unterstützung, welches insbesondere durch informelle soziale Systeme (Kontaktmöglichkeiten) positiv beeinflusst wird. Die Entwicklung informeller interdisziplinärer Netzwerke reduziert die Barrieren der Zusammenarbeit, erleichtert den Informationsfluss und beschleunigt Entscheidungen.

Jedoch birgt die interdisziplinäre Zusammenarbeit neben den bereits vorgestellten Risiken, personenbezogene Barrieren, die sich aus den unterschiedlichen Denkwelten (Fachrichtungen), unterschiedlicher Sprache und verschiedenen Persönlichkeiten ergibt.

5 Agile Prozessgestaltung und Erfolgsfaktoren in komplexen Prozessen

Um der Komplexität im Produktionsanlauf bedingt durch interdependente Gestaltungsobjekte und Disziplinen, der damit verbundenen Interdisziplinarität, zu begegnen und umzugehen, lässt sich der systemische Denkansatz zu Hilfe nehmen. Dies heißt u.a. die Prozesse nach dem Subsidaritätsprinzip so dezentral wie möglich und so zentral wie nötig zu organisieren, aber auch den Umgang mit Unsicherheit zu erlernen und mit Widersprüchen leben können und zugleich Konkurrenz und Kooperationen zu managen [Hen93]. Eine weitere wichtige Eigenschaft beim systemischen Denken und Handeln ist die „Reduktionsweisheit". Dies meint in komplexen Zusammenhängen genau diejenigen kritischen Zentralursachen sowie Hebelpunkte zu finden [Rie00]. In diesem Zusammenhang zeigt Henning Agilität als Fähigkeit mit zunehmender Komplexität umgehen zu können auf und formuliert in Anlehnung an das agile Manifest der Softwareentwicklung aus dem Jahre 2001 (vgl. Agile Manifest der Softwareentwicklung 2001 abrufbar unter: www.agilemanifesto.org.) nachfolgende Werteabwägung des agilen Manifest der Prozessgestaltung [Hen08]:

- Uns sind Individuen und Interaktionen wichtiger als Prozesse und Werkzeuge.
- Uns sind lauffähige Prozesse wichtiger als umfangreiche Dokumentation.
- Uns ist die Zusammenarbeit mit dem Kunden wichtiger als Vertragsverhandlungen.
- Uns ist es wichtiger auf Änderungen reagieren zu können, als einen Plan zu verfolgen.

Daher messen wir, obwohl die jeweils zweiten Dinge ihren Wert besitzen, den jeweils erstgenannten Dingen höheren Wert zu [Hen08].

Insgesamt rückt das agile Manifest der Prozessgestaltung den Menschen und seine Interaktionen mit dem Fokus auf laufende Prozesse in den Mittelpunkt. Zur Konkretisierung dieser Werte und zur Abbildung eines agilen Prozesses lassen sich folgende zwölf Prinzipien formulieren:

1. Höchste Priorität haben die Bedürfnisse des Kunden.
2. Nutze unbeständige Anforderungen und Änderungen zu Gunsten des Wettbewerbsvorteils des Kunden.
3. Häufige Auslieferungen helfen, die Komplexität zu reduzieren.
4. Zusammenarbeit von Kunden und Produzenten ist unerlässlich.
5. Schaffe Vertrauen, damit die Mitarbeiter motiviert arbeiten können.
6. Direkte Kommunikation ist oft besser als indirekte.
7. Funktionierende Prozesse sind der Maßstab des Erfolgs.
8. Sorge für ein endlos beständiges Tempo.
9. Strebe nach exzellenter Qualität.
10. Suche nach Einfachheit.
11. Fördere sich selbst organisierende Teams.
12. Regelmäßige Selbstreflexion ist ein „Muß".

Diese Prinzipien wurden in einem außerordentlich schwierigen IT-Projekt zur Einführung des LKW-Mautsystems „Toll Collect" in Deutschland angewandt [KH08]. Dabei stand das Projekt während seiner Laufzeit mehrfach vor dem Scheitern. Zur Identifikation des Problems wurden im Projekt typische Projektrisiken überprüft und es zeigte sich, dass die Technologien keine besondere Risiken bargen, da nur auf bewährte Technologien zurückgegriffen wurde. Die Architektur konnte ebenfalls nicht als risikoreich klassifiziert werden, da hauptsächlich sauber definierte und stabile asynchrone Schnittstellen die Teilsysteme verbinden sollten. Ein mittleres Projektrisiko konnte bei der Anzahl der Lieferanten und Standorte definiert werden, da acht Lieferanten an fünfzehn Standorten zusammenarbeiten mussten. Hingegen bestand ein hohes Projektrisiko in der Komplexität der Aufgabe aufgrund der hohen Performance-, Last- und Sicherungsanforderungen sowie ein sehr hohes Risiko im unrealistischen vorgegebenen Zeitplan, der keinen Raum für unvorhersehbare Probleme vorsah [KH08].

Der fest vorgegebene Zeitplan sowie detaillierte und gesetzlich per Vertrag definierte Anforderungen führten dazu, dass das Projekt vom ersten Tag an als extrem kritisch einzustufen war. Nachfolgend aufgeführte Erfolgsfaktoren sind ex-post als die wesentlichen identifiziert worden [KH08]:

1. Sich der Komplexität und Schwierigkeit der Situation immer wieder uneingeschränkt bewusst werden.
2. Allen Ballast über Bord werfen.
3. Technik bauen, die „gut genug" ist.
4. Die internen Prozesse durch straffes Prozessmanagement optimieren.
5. Kooperation und Kommunikation ständig verbessern.
6. Ein Kern-Team aufbauen, das weiß, wovon es redet und sich 100 % auf den Erfolg konzentriert.
7. Vertrauen und Zuversicht (wieder) aufbauen.
8. Arbeiten, arbeiten und noch mal arbeiten.

Vergleicht man diese aus der Praxis abgeleiteten Erfolgsfaktoren mit den agilen Prinzipien, so zeigt sich, dass ein Teil dieser Prinzipien als Grundlage zum Management komplexer Prozesse auch im Praxisprojekt bewährt haben. Allerdings gibt es auch Aspekte, die nicht mit den praktischen Erfahrungen übereinstimmen. So ist z. B. der agile Maßstab „Exzellente Qualität“ offensichtlich bei wachsender Komplexität nicht durchzuhalten. „Gut genug“ anstelle „exzellent“ kennzeichnet dabei den Fokus „notwendige Qualität“ zu erzeugen und nicht die Beste [HTB05].

6 Agile Prozessgestaltung und Erfolgsfaktoren im Produktionsanlauf

Die Anwendung der zuvor vorgestellten Erfolgsfaktoren auf das Management des Produktionsanlaufs ist je nach Anwendungsfall unterschiedlich und zeigt eine differenzierte Ausgestaltung der einzelnen Prinzipien und Ausrichtung auf die Erfolgsfaktoren auf.

Im Rahmen eines weiteren Praxisbeispiels zum Produktionsanlauf eines mechatronischen Produktes wird die Ausgestaltung der formulierten Prinzipien aufgezeigt. Identifizierte Komplexitätstreiber in diesem Produktionsanlauf waren die interdisziplinäre Aufstellung des Projektteams mit Mitgliedern aus den Bereichen Usability, IT, Mechanik, Hardware sowie eine Netzwerkorganisation bei der sich die Entwicklungsleistung der Software auf zahlreiche Zulieferer aufteilte. Sowohl das agile Manifest der Prozessgestaltung und die abgeleiteten Prinzipien als auch die Erfolgsfaktoren für komplexe Projekte wurden dabei angewandt. Des Weiteren stand die Erarbeitung eines gemeinsamen Prozessverständnisses im Vordergrund, welches unter anderem während der komplexen Workshopreihen erarbeitet wurde.

Die in Abb. 4 dargestellten Reviews wurden im Projektverlauf mit unterschiedlichen Teilnehmerzahlen aus verschiedenen Hierarchieebenen durchgeführt, dies folgt dem Prinzip der regelmäßigen Selbstreflexion und dem Erfolgsfaktor „Sich der Lage immer wieder bewusst werden“. Die im Rahmen der Academy durchgeführten Veranstaltungen führten zu einer kontinuierlichen Weiterbildung der Teilnehmer und der Erarbeitung einer gemeinsamen Wissensbasis, die im vorherrschenden interdisziplinären Kontext wie bereits eingangs erläutert, von besonderer Bedeutung für die produktive Zusammenarbeit ist.

Die mehrtägigen Workshops in der sog. Ramp Up Phase (Produktionsanlauf), in diesem Fall Übergang vom zweiten Meilenstein zum Serienstart, sind inhaltlich getriebene, iterativ gestaltete Prozesse, die parallel von kontinuierlichen Meetings und Statusberichten begleitet wurden. Hierbei stand die Selbstorganisation der Teams und Förderung der Kommunikation im Vordergrund. Dieses Workshopkonzept, das moderierte, aufeinander aufbauende, mehrtägige Treffen vorsieht, wurde ebenfalls im Rahmen des Dokumentenmanagements zur Prozessunterstützung und somit zur Optimierung der internen Prozesse (Erfolgsfaktor 4) eingesetzt.

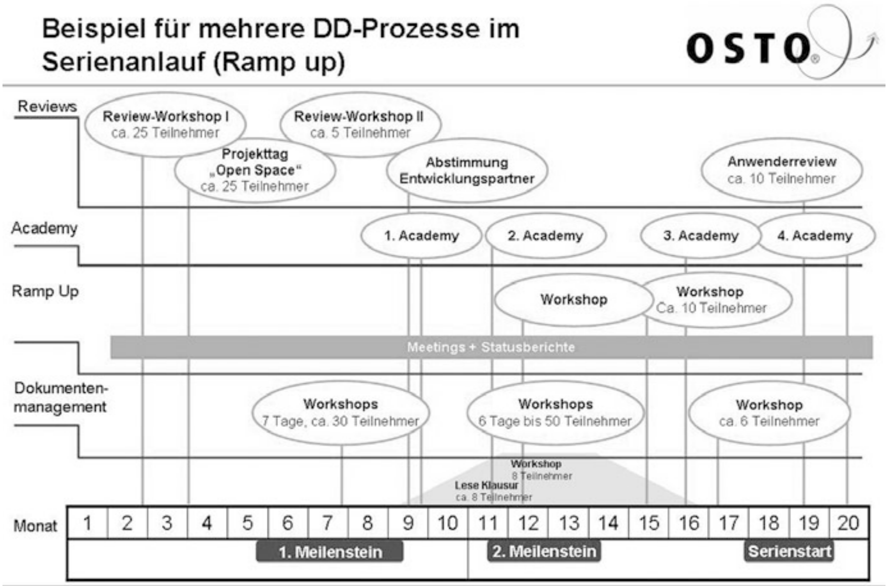

Abb. 4 Beispiel für Gestaltung des Beleitungsprozesses im Produktionsanlauf [OST10]

7 Zusammenfassung und Ausblick

Eine agile Vorgehensweise, die sich nicht nur auf den Softwareentwicklungsprozess bezieht, sondern ebenso auf das Management des Produktionsanlaufs, kann in einem zeitkritischen komplexen Entwicklungsprojekt erfolgreich angewendet werden. Dabei bedeutet dies für alle Akteure die Grundwerte und -prinzipien des agilen Manifestes praxisnah umzusetzen und die gesamte Managementstruktur nach dem Dynaxityprinzip für turbulente Prozesse mit hoher Struktur- und Prozesskomplexität sowie einer Orientierung an den Erfolgsfaktoren für komplexe Prozesse ausgelegt werden. Beide Vorgehensweisen stammen aus unterschiedlichen Akteursgruppen in Wissenschaft und Praxis. Das Fallbeispiel zeigt, dass sie sich erfolgreich miteinander verknüpfen lassen. Turbulenztaugliches Systemisches Management und Agile Softwareentwicklung können so zu einem Gesamtvorgehensmodell zusammengeführt werden, das zum Management des Produktionsanlaufs eingesetzt werden kann.

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Standard Operating Procedures for Telemedical Care in Emergency Medical Services

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Sabina Jeschke

Abstract The introduction of standard operating procedures (SOPs) in emergency medical services (EMS) provides an opportunity to increase treatment quality and efficiency of rescue operations. This paper presents the concept of SOPs for an application of telemedical care in EMS. We developed SOPs for all main processes and devices used in TemRas (Telemedical Rescue Assistance System) and especially for single disease patterns which will support tele-EMS physicians providing a guideline-oriented patient care during a one year trial.

Key words: Telemedicine, EMS, SOP, Quality Improvement

1 Introduction

Within the research project TemRas (Telemedical Rescue Assistance System) a telemedical care system, enabling live teleconsultation among EMS teams on site and EMS physicians afar from the patient is developed and implemented to increase the quality of emergency missions in Germany. The objective is the introduction of a tele-EMS physician providing medical support for the EMS team on site by automatically transmitting audio and video data, as well as vital signs and 12-lead-ECG from the emergency site to a teleconsultation centre [TSSJ11]. The transmitted data as well as additional and more extensive sources of information like poison control centres or medical databases allow the tele-EMS physician to gain a comprehensive insight of the patient and support the EMS team on site according to the necessary

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treatment. This is particularly shortening the time to definite treatment within EMS and improving the quality of care [SBB+11].

Within this paper, the concept of standard operating procedures (SOPs) developed for the trial run of the TemRas project is presented. The SOPs, interactively used by the tele-EMS physicians during teleconsultation, serve as guidelines to result in a consistent, uniform and high quality treatment of the patient by the EMS team on site. Therefore an application is developed for an intuitive handling of the SOPs whose contribution to a process optimization is examined within a trial run. SOPs have been proved to be efficient and quality-increasing in clinical settings and surgery [SBS08]. These findings are now transferred to an application of telemedicine in EMS.

2 Basic Idea of Standard Operating Procedures

SOPs have the purpose of detailing the regularly recurring work process that is to be conducted or followed in an organization. They document the way activities should be performed to facilitate consistent conformance to quality system requirements. They may describe e.g. the adequate use of equipment, or guideline-oriented operations. SOPs are intended to be specific to the organization whose activities are described and assist that organization to maintain their quality control and assurance processes as well as to ensure compliance with governmental regulations [Uni07].

SOPs can be very helpful to standardization, integration and transfer of knowledge. They minimize the variation of workflows with different characteristics, and improve the efficiency and quality of services in the organization. Besides, SOPs should be written in a certain styles. The document should be written in a simple, step-by-step, easy-to-read format. Information should be conveyed clearly to remove any doubt as to what is required. The use of flow charts to illustrate the process being described is as important as following the style guide used by the organization [Eur02].

These rules are very significant to SOP's implementation and followed in this application. The objectives of the TemRas specific SOPs are:

- Transmission of knowledge (training documents) and set of standards in which SOP help making decisions, but they do not replace them
- Support and assurance of TemRas-related processes during trial run and increase of transparency of health care with the use of checklists
- Assistance with documentation in the teleconsultation centre.

3 Methodology

Based on the described requirements and the framework of the TemRas project we identified five content-specific categories of SOPs. A first category contains the general concept of SOP as well as its creation, publication and specifications of the

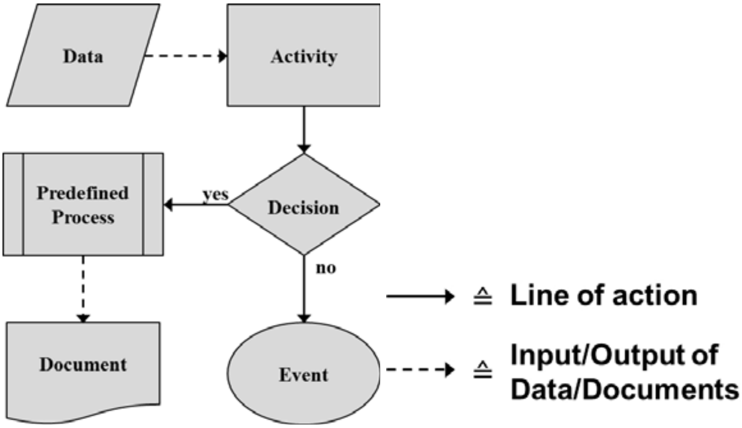

Fig. 1 Elements for SOP flow charts

change management process. The successful use of SOPs in the context of EMS missions is facing the challenge of adequate visualization as the tele-EMS physicians follow the SOP simultaneously to teleconsultation. Therefore a one-sided flow chart presenting the particular process in a catchy method with a notation according to DIN standard 66001which is used in standardization of production processes has been adopted for the use in TemRas (Fig. 1) [66083].

Besides the flow chart the actual SOP contains additional information. Other categories contain SOPs for handling the hardware and software of the system in the ambulance and the teleconsultation centre as well as support and maintenance processes. An interdisciplinary team of engineers, computer scientists and physicians have worked together to create and implement the SOPs within the research project TemRas.

The most important SOPs contain medical treatment procedures for several disease patterns which guarantee a guideline-based patient care in the interaction of tele-EMS physicians and the EMS teams on site. These SOPs range from the arrival of the EMS team on site and anamnesis up to the application of medication and the accurate transfer for further treatment. This includes using the different components of the TemRas System. Thus, the tele-EMS physicians derive a high qualified treatment of the patients e.g. for hypoglycaemia, acute coronary syndrome, chronic lung disease or stroke while following established standards like SAMPLE and ABCDE.

4 Implementation

As described above, the flow chart is the main element of each SOP. Especially the medical SOPs have to be used interactively by the tele-EMS physicians to guarantee a high quality treatment for each patient. Therefore the framework of Microsoft

PowerPoint and its slide show format pps have been used. Each flow chart is complemented with additional hyperlinks and literature to provide the tele-EMS physician with additional information. For important process steps or medicine applications this information is integrated into the document as mouse over popups. The level of detail has been adjusted in order to visualize the entire process on one page.

This structure can be perfectly integrated into the entire software system of TemRas and provides e.g. interfaces for checklists and parts of the documentation. Thus the SOPs guide the physician through all processes of teleconsultation and medical treatment.

5 Conclusion and Outlook

By developing this concept and implementing all necessary SOPs, the basis for the trial run within the research project TemRas is given. SOPs are a main part of training material for the EMS staff as well as the tele-EMS physicians while they become acquainted with the TemRas-specific devices. Furthermore SOPs provide guidance for all processes, particularly the medical treatment algorithms which results in a consistent, uniform and high quality treatment for patients by the EMS team on site. For this application the implementation of SOPs with Microsoft PowerPoint and its pps files is an optimal solution. It is easy to handle and almost available and capable of being integrated everywhere. The whole concept of SOPs will be validated for its impact on the use of medical treatment via teleconsultation in a one year trial run starting in August 2012.

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Langfristiges Verstehen durch kurzfristiges Missverstehen. Die Bedeutung der interaktiv-transkriptiven Störungsbearbeitung für den Transfer von Wissen

Max Haarich, Ingo Leisten, Frank Hees, Sabina Jeschke

Zusammenfassung Der Artikel stellt die Problematik des Wissenstransfers im Bereich anwendungsorientierter Forschungsprogramme als Konsequenz einer universellen Ausdifferenzierung von Wissensgebieten und Sprachspielen dar. Aus konstruktivistischer Perspektive werden Lösungsvorschläge abgeleitet, die auf die gemeinschaftliche Bearbeitung kommunikativer Störungen durch die Transferpartner abzielen. Hierin wird der Schlüssel zur Überwindung von Wissens- und Sprachspielgrenzen sowie zur Generierung und zum Transfer von Wissen vermutet. Am Beispiel des Forschungs- und Entwicklungsprogramms des Bundesministeriums für Bildung und Forschung (BMBF) „Arbeiten – Lernen – Kompetenzen entwickeln. Innovationsfähigkeit in einer modernen Arbeitswelt“ werden Maßnahmen aufgezeigt, um das den kommunikativen Störungen innewohnende Potenzial zur Kompensierung der Transferproblematik auszuschöpfen.

Schlüsselwörter: Wissenstransfer, Präventiver Arbeits- und Gesundheitsschutz, Transkriptionstheorie.

1 Einleitung

Sowohl Forscher als auch Praktiker des Präventiven Arbeits- und Gesundheitsschutzes bemängeln die Effizienz und Effektivität des Wissenstransfers zwischen beiden Gruppen. Ansätze zur Verbesserung des Wissenstransfers beschränken sich meist auf die Optimierung der Vermittlung des Wissens. Das Transferproblem beginnt jedoch schon bei der Produktion von Wissen. Das Wissen aller Forschungsdisziplinen wird in erster Linie sprachlich kodiert, somit setzt der Zugang zum produzierten Wissen das Verstehen der verwendeten Ausdrücke, also der Worte und Formu-

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lierungsweisen voraus. Problematisch wird das interdisziplinäre Verstehen, wenn bestimmte Ausdrücke einem der Transferpartner gar nicht bekannt sind oder aber von beiden Transferpartnern unterschiedlich verwendet werden. Es kommt zu einer kommunikativen Störung, die eine Klärung der fehlenden oder irritierenden Ausdrucksbedeutung erfordert. Die Transkriptionstheorie zeigt aus konstruktivistischer Perspektive, dass die Prozesse der Produktion und der Vermittlung von Wissen stets auf der interaktiven Klärung dieser kommunikativer Störungen beruhen. Eine wichtige Frage ist daher, wie das kommunikativen Störungen innewohnende Potenzial für den Transfer von Wissen ausgeschöpft werden kann, wie Missverstehen zu Verstehen werden kann.

2 Die Symptomik des Transferproblems in der Präventionsforschung

Unter dem Transferproblem subsummiert man disziplinenübergreifend sämtliche Faktoren, die eine mangelhafte Wahrnehmung und Anwendung wissenschaftlicher Forschungsergebnisse in der Praxis bewirken. Die Ergebnisse des Metaprojektes StArG weisen darauf hin, dass die Transferproblematik auch im Präventiven Arbeits- und Gesundheitsschutz noch nicht abschließend gelöst ist. Praktiker beklagen weiterhin die teilweise mangelnde Praxisrelevanz wissenschaftlicher Forschungsergebnisse, Forscher bemängeln die fehlende Umsetzung der wissenschaftlichen Ergebnisse im unternehmerischen Handeln. Der Grund wird dabei oftmals im Scheitern von Transfer gesehen. Doch was versteckt sich hinter dem Ausdruck „Transfer"? [HLBH09] weisen darauf hin, dass es notwendiger Weise einer Spezifizierung des Transfer-Begriffs bedarf:

- Transfer im Sinne von Breitentransfer meint die Entwicklung und Gestaltung eines Forschungs- bzw. Wissenschaftsmarketings. Für den Präventiven Arbeits- und Gesundheitsschutz heißt dies insbesondere die Notwendigkeit von Öffentlichkeitsarbeit, die vor allem die Stakeholder der Präventionslandschaft anspricht.
- Transfer im Sinne von Tiefentransfer bezieht sich auf die kooperative Forschungsarbeit (vor allem auf Projektebene). Dazu werden Konzepte zur Wissensgenerierung und Handlungsumsetzung benötigt, die eine kooperative Zusammenarbeit in Akteursallianzen zwischen Forschern, Praktikern und Intermediären fördern. Besonders durch interaktive Methoden des Tiefentransfers können Forschungsergebnisse des Präventiven Arbeits- und Gesundheitsschutzes einen sichtbaren und nachhaltigen Einfluss auf das Verhalten der Praktiker vor Ort erzielen.

In diesem Artikel wird aus konstruktivistischer Perspektive beleuchtet, wie durch Kommunikations- und Kooperationsentwicklung ein Beitrag zur Gestaltung des Tiefentransfers geleistet werden kann. Wie Untersuchungen im Metaprojekt StArG aufzeigen, sind die Gründe für die viel zitierte Transferproblematik nicht nur in für den Präventiven Arbeits- und Gesundheitsschutz spezifischen Ursachen zu suchen, sondern sind teilweise universeller Natur [Haa10]. Das Wissenstransferproblem lässt sich auf ein Problem anwachsender Komplexität – zum einen des gesellschaftlichen Wissenshaushaltes und zum anderen der bei der Wissensproduktion verwendeten „Sprachspiele", d. h. der disziplinenspezifischen Ausdrücke und Formulierungsweisen – zurückführen.

Die Gründe für die häufig mangelnde Praxisrelevanz von Forschungsergebnissen vermuten [HLBH09] in der prinzipiellen Divergenz zwischen den forscherischen und unternehmerischen Zielsetzungen sowie der zum Teil mangelhaften Fähigkeiten der Praktiker, akute Forschungsbedarfe zu formulieren. Verstärkt wird diese Symptomatik durch die schwache Ausprägung von Rückkopplungsmechanismen, mittels derer Wissenschaftler Praxiswissen zur Ausrichtung ihrer Forschungsaktivitäten erhalten. An dieser Stelle zeigt sich, dass strategische Transferkonzepte nicht erst bei der Vermittlung, sondern schon bei der Produktion von Wissen ansetzen müssen. Somit ist die Transferproblematik, wie [Lud07] betont, unter zwei Perspektiven zu betrachten: als Problem der Vermittlung, aber auch der Produktion von Wissen. „Das Wissenstransferproblem beginnt bereits während der Entstehungsphase von Wissen" [Lud07].

Im Rahmen einer explorativen und qualitativen Akzeptanzbefragung [HLR07], ermittelte das Metaprojekt StArG weitere transferhemmende Faktoren:

a) Forschungseinrichtungen fördern den Transfer wissenschaftlicher Ergebnisse häufig nicht im nötigen Maße.
b) Die Vor- und Nachteile einzelner Transfermethoden sind den Forschern meist nicht ausreichend bewusst.
c) Das Potenzial direkter mündlicher Kommunikation wird kaum erkannt.

a) Wie die Befragung u. a. zeigt, ist die Planung, Entscheidung und Durchführung des Transfers selten Aufgabe des Führungspersonals oder speziell ausgebildeter Organisationsschnittstellen. Meist obliegt der Transfer der erzielten Ergebnisse dem forschenden Mitarbeiter selbst. Eine hierbei förderliche organisationale Weiterentwicklung von Transferkompetenz ist nur marginal ausgeprägt. Dieser Missstand ist keineswegs beschränkt auf den Präventiven Arbeits- und Gesundheitsschutz. Wie [SV06] bemerken, wird der Transfer von Forschungsergebnissen meist als quasi-automatischer „Spill-Over-Effekt" [SV06] betrachtet und der Verantwortung des Mitarbeiters überlassen, der dafür auch nur selten die finanzielle oder fachlich/wissenschaftsinterne Würdigung erhält.
b) Gleichzeitig verfügen Forscher des Präventiven Arbeits- und Gesundheitsschutzes nach eigener Einschätzung häufig nur über mangelhafte Kenntnis hinsichtlich der Wirkung einzelner Transfermethoden. Der Erfolg von Transfer(-Methoden) wird selten reflektiert und meist nur ‚indirekt' evaluiert, indem er mit dem Erfolg des Gesamtprojektes gleichgesetzt wird.
c) Weiterhin zeigen Aussagen der Akzeptanzbefragung, dass Formen der direkten mündlichen Kommunikation zwar bei der Akquise von Wissen bevorzugt eingesetzt, aber als Transferinstrument überhaupt nicht wahrgenommen werden. So beschränkt sich die externe Kommunikation von Forschungswissen vornehmlich auf schriftbasierte Kommunikation via Fachartikel.

3 Das Transferproblem als universelles Problem in der Forschung?

Die Problematik der Produktion und Vermittlung von Wissen ist jedoch nicht auf spezifische Ursachen im Präventiven Arbeits- und Gesundheitsschutz zurückführen, sondern resultiert aus universellen Ursachen, die allen Wissenschaften zugrunde liegen (siehe Abb. 1).

Die Ursache des Transferproblems identifiziert [Jäg96] in der Komplexitätssteigerung des Wissens und der Sprache, ausgelöst durch die Literalisierung Europas. Die Verbreitung des Buchdrucks und der Lese- und Schreibkompetenz ermöglicht eine enorme Leistungssteigerung der Wissenschaften. Die Speicherkapazität des Mediums Schrift erlaubt es Wissensmengen anzuhäufen, welche den potenziellen Wissensschatz eines einzelnen Individuums um ein Vielfaches übertreffen. Das Individuum ist nicht mehr fähig, alles relevante Wissen selbst zu speichern, sondern muss sich auf bestimmte Wissensbereiche spezialisieren. So realisiert sich die Wachstumssteigerung des Wissens zwangsläufig in einem Prozess der Ausdifferenzierung des Wissens in modularisierte Expertenwissensgebiete.

Der gerade skizzierte Ausdifferenzierungsprozess des Wissens allein vermag das Transferproblem jedoch nicht zu begründen. Von hieraus lässt sich lediglich erklären, warum – um als Beispiel zwei Teildisziplinen des Präventiven Arbeits- und Gesundheitsschutzes heranzuziehen – ein Forscher aus der Medizin meist ein anderes Wissen hat als ein Forscher aus den Arbeitswissenschaften. Nicht berücksichtigt wurde bisher, dass die Ausdifferenzierung des Wissens unweigerlich gekoppelt ist an eine parallele Ausdifferenzierung der Sprache bzw. der Sprachspiele [Jäg96]. Die Fortentwicklung von Wissenschaften ist meist erst durch die Spezifizierung von Sprachspielen, also Fachterminologien und Formulierungsweisen realisierbar, die sich innerhalb eines Experten-wissensgebietes etablieren, disziplinfremden Forschern jedoch unzugänglich bleiben.

Dies kann sich zum einen auf Ausdrücke beziehen, die in der beiden Forschergruppen gemeinsamen Alltagssprache nicht verwendet werden oder zum anderen um eine hoch-spezifische Verwendung der Alltagsausdrücke, die mit der alltagssprachlichen Verwendung jedoch nicht mehr vereinbar ist. Während als Beispiel für Ersteres ein kurzer Blick in ein medi-zinisches Fachlexikon genügt, wäre die unterschiedliche Besetzung des Ausdrucks „Netzwerk“ in der Soziologie und in der Informatik ein Beispiel für den zweiten Fall von divergierenden Ausdrucksverwendungen, die die interdisziplinäre Kommunikation stören und den Wissenstransfer zunächst hemmen.

> In gewissem, wohlbestimmten Sinne ist die Wissenschaft, damit auch ihre Sprache unvermeidlicherweise unverständlich. [. . .] Wissenschaft, verständlich gemacht, verliert ihre Wissenschaftlichkeit [. . .] [Mit98]

Das Transferproblem lässt sich also nicht darauf reduzieren, dass Wissen zwischen Experten-gruppen ungleich verteilt ist – dies ist die notwendige Voraussetzung für Wissenstransfer. Hinzu kommt, dass das produzierte Wissen mittels eines

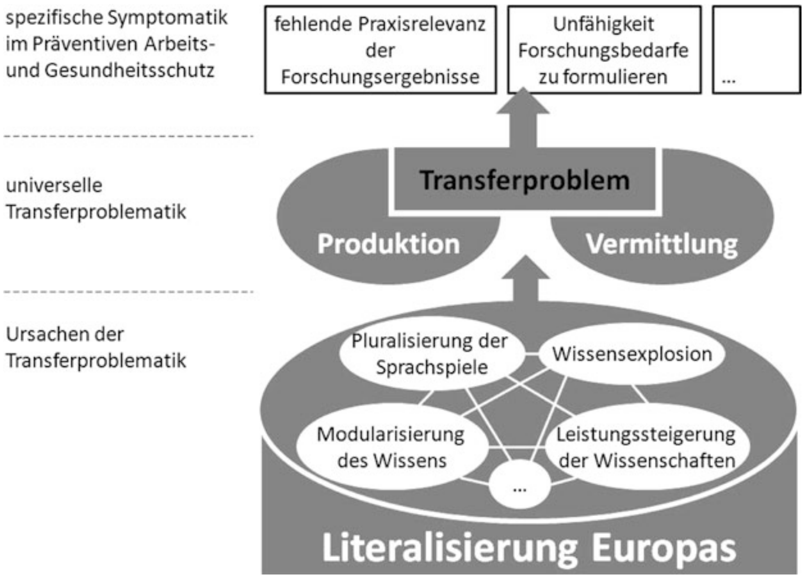

Abb. 1 Das Transferproblem: Ursachen und Symptomatik

Sprachspiels kodiert wird, welches fachfremden Laien und Experten schwer zugänglich, jedoch für die Genese des Wissens konstitutiv ist.

Eine eigentümliche Entwicklung zeichnet sich ab, die [Ant01] mit einem „Circulus Vitiosus“ [Ant01] vergleicht: „Das Wissen wächst, aber die mögliche Teilnahme an Wissen nimmt ab“ [Jäg96]. Es erhöht sich die „Opazität“, also die Unüberschaubarkeit des vorhandenen Wissens [Ant01] und bewirkt ein „Retrieval Problem“ [Ant01], da die Komplexität der Wissenschaft sowie der Sprachspiele einer einfachen Identifizierung relevanten Wissens entgegenwirken und es an komplexitätsreduzierendem Metawissen mangelt. Die Modularisierung des Wissens und die Ausdifferenzierung der Sprachspiele sind die unvermeidliche Kehrseite der Leistungssteigerung der Wissenschaft. Der Wissensgewinn einer Disziplin kann i.d.R. nur auf Kosten der Verständlichkeit des Wissens gegenüber Disziplinfremden realisiert werden. Heute bestehen „die neuen Zugangsschranken zum Wissen in der Herausbildung spezialisierter Sprachspiele, die jeweils nur für kleine Gruppen von Experten nutzbar sind“ [Jäg96].

Für den Präventiven Arbeits- und Gesundheitsschutzes deutet sich folgende Erklärung des Transferproblems an: Eine modularisierte Forschungsdisziplin produziert für die Praxisexper-ten Wissen in einem Sprachspiel, welches mit dem Sprachspiel des ebenfalls modularisierten Praxisbereiches zwangsläufig nicht vollständig kompatibel ist.

Wie kann dem Transferproblem nun entgegnet werden, wenn man die dafür verantwortliche „Wissensexplosion“ [Dew05] als irreversibel und unaufhaltsam ansieht [Spi99, Kro97]? Lösungsversuche können somit nicht bei der Dispersion des Wissens, sondern erst bei deren Konsequenzen, der Modularisierung des Wissens und der Ausdifferenzierung der Sprachspiele, ansetzen. Dementsprechend strebte Leibniz bereits im 17. Jhdt. eine Scientia Generalis an, welche alle Expertensprachspiele in einer einheitsstiftenden Metasprache vereinen sollte [Mit98]. Moderne Wissenschaften sind jedoch schlichtweg angewiesen auf maßgeschneiderte Fachterminologien, um komplexe Zusammenhänge effizient kommunizieren zu können und würden durch eine Nivellierung der Experten-sprachen um ein wichtiges Element ihrer Leistungsfähigkeit beraubt [Mit98].

Eine mögliche Lösung besteht daher nicht im Erlernen einer einzigen allumfassenden Wissen-schaftssprache, sondern in der Aushandlung je spezifischer Meta-Sprachspiele, mittels derer zwischen jeweils zwei bestimmten modularisierten Wissensgebieten kommunikativ vermittelt und Wissen transferiert werden kann. Die im Folgenden skizzierte Transkriptionstheorie von Ludwig Jäger weist die interaktive Bearbeitung kommunikativer Störungen als den Prozess aus, in dem gemeinsam ein solches Sprachspiel gebildet sowie Wissen produziert und vermittelt wird.

4 Die Transkriptionstheorie als Lösungsraum für die Transferproblematik

Ludwig Jäger bietet mit seiner Transkriptionstheorie einen medientheoretischen Gegenentwurf zu gängigen Semantiktheorien, indem er ontologische Betrachtungsweisen von Kommunikationsmedien durch eine prozessorientierte Sichtweise ersetzt. Gemäß seiner Theorie können Kommunikate – beispielsweise schriftliche Texte, Tabellen, Bilder, Filme, gesprochene Texte usw. – niemals aus sich heraus Semantik bzw. Wissen bereitstellen, sondern nur aus Verfahren der Kopplung mit anderen Medien [jag08]. Ein schriftlicher Text muss durch Sprache, sei dies auch nur ein gedachtes Sprechen des Rezipienten, transkribiert werden, um dadurch für die Wissensgenese fruchtbar zu werden; mediale Strukturen müssen in mentale Strukturen transkribiert werden [Jäg01].

Transkription kann als eine Art sprachlicher Prozess der klärenden Bearbeitung von Kommunikaten verstanden werden. Sie richtet sich auf jegliche Äußerungen, die unser Transferpartner im Modus der Mündlichkeit oder Schriftlichkeit produziert und überführt das Rezipierte in subjektives Wissen, sofern uns die Kodierungsweise, d. h. das Sprachspiel des Transferpartners vertraut ist. Stoßen wir auf irritierende bzw. störende Ausdrucksverwendungen, sei es, weil wir den Ausdruck nicht kennen oder für gewöhnlich anders verwenden, sind es ebenfalls transkriptive Bearbeitungsprozesse, die uns zum Verstehen des Vernommenen leiten, wenn wir den Transferpartner beispielsweise um Erklärung oder Paraphrasierung des Gemeinten bitten. Innerhalb dieser Bearbeitungsprozesse wird es beiden Transferpartnern ermöglicht, die mit ihrer Ausdrucksverwendung verbundenen impliziten Wissensbestände in einer Weise zu explizieren, dass sie dem Gegenüber zugänglich werden. Dadurch gewinnen die Transferpartner sowohl Einblick in das Sprachspiel des Gegenübers, als auch in seinen spezifischen Wissensvorrat. Die gemeinsame Bearbeitung kommunikativer Störungen erweist sich als notwendige Bedingung für

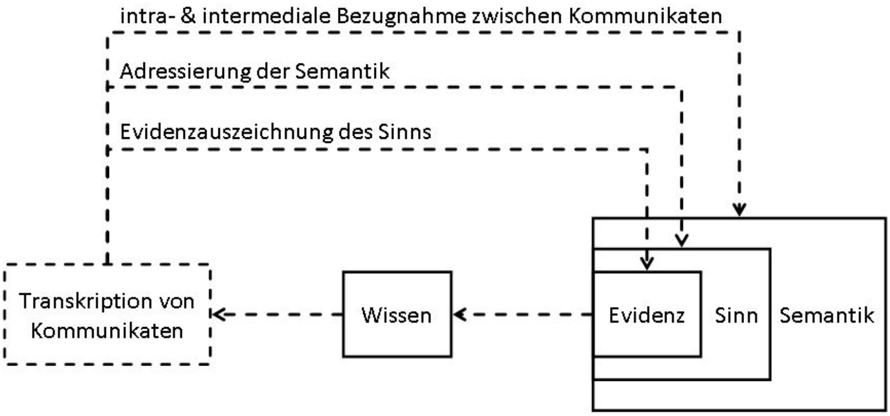

Abb. 2 Transkriptive Prozesse. Nach [jag08]

den Transfer von Wissen und das Erlernen eines gemeinsamen Sprachspiels zum besseren Verständnis des Transferpartners.

Jäger sieht diese Prozesse darüber hinaus nicht nur für das Verstehen der Intentionen des Transferpartners verantwortlich, sondern genauso auch – und das ist eine weitere Besonderheit von Jägers Sprachphilosophie – für das Verstehen unserer eigenen Kommunikate. Erst die größtenteils unbewusste Bearbeitung unserer eigenen Kommunikate durch die Transkription der medialen Strukturen zurück in mentale Strukturen, ausgelöst durch ebenso unbemerkte Selbst-Störungen, erlaubt uns nachträglich das wirkliche Verstehen unserer eigenen Äußerung. Transkriptives Prozessieren versteht Jäger somit als Grundmodus jeglichen Verstehens, der durch teils unbewusste, teils offen diskutierte kommunikative Störungen ausgelöst wird.

4.1 Der Übergang von Information zu Wissen

Jäger versteht Wissen stets als Resultat dreier Funktionen transktiptiver Prozesse, innerhalb derer Informationen vom Rezipienten selbst mit Semantik, Sinn und Evidenz versehen werden (siehe Abb. 2). Danach ist Semantik allein noch kein Wissen, vielmehr muss die Semantik eines in der Kommunikation verwendeten Kommunikats zunächst den Rezipienten spezifisch adressieren, und zwar durch die Wahl einer angemessenen Transfermethode. Erst dadurch wird der Rezipient befähigt, der Semantik des Kommunikats einen individuellen pragmatischen Gebrauchssinn zuzuweisen, wodurch sie für ihn „lesbar“ wird [jag04a]. Stattet der Rezipient die lesbare Semantik abschließend mit Evidenz aus, d. h. erkennt er die vermittelte Semantik als gültig an, kann er aus der Semantik Wissen ableiten und bei zukünftigen Transkriptionen darauf zurückgreifen.

Als Beispiele könnte man sich eine Kampagne zur Vorbeugung vor dem Repetitive Strain Injury Syndrom (RSI) mittels der Verbreitung medizinischer Fachartikel denken. Angehörige der möglichen Zielgruppen, Menschen, die einen Großteil ihrer Arbeit am PC erledigen, wissen möglicherweise, dass es sich bei RSI um eine Erkrankung durch wiederkehrende Belastung handelt, die häufig die Handgelenke betrifft. Dies wäre zunächst die Semantik des Ausdrucks, die dadurch zustande kommt, dass die geschriebenen Worte in gedachte Worte transkribiert werden; vom Modus der Schriftlichkeit in den Modus der Mündlichkeit überführt werden. Damit die Kampagne jedoch im Sinne des Tiefentransfers auch zu einer Verhaltensänderung führt, muss die Semantik des Ausdrucks durch die Wahl eines passenden Transfermediums als zweites lesbar gemacht werden. Ein kurzes Aufklärungsvideo, welches falsche von richtigen Handstellungen beim Schreiben am PC unterscheidet wäre für die meisten Menschen lesbarer als die bereits vorhandenen medizinischen Arbeiten zu diesem Thema, da Nichtwissenschaftler selten an die Verwendung von medizinischen Fachartikeln zur Ableitung von Wissen gewöhnt sind. In letzter Konsequenz liegt es jedoch wiederum am Rezipienten, der lesbaren Semantik des Videos als drittes Evidenz, also (scheinbar) objektive Gültigkeit zuzusprechen, als Basis für die angestrebte Verhaltensänderung. Der Rezipient hat nun ein Wissen über das Repetitive Strain Injury Syndrom erworben, welches ihm bei der nächsten Diskussion über dieses Thema für transkriptive Bearbeitungsprozesse zur Verfügung steht. Die drei beschriebenen transkriptiven Prozesse vollziehen sich dabei nicht isoliert, sondern sind als drei zu synthetisierende Momente derselben Transkription anzusehen, und werden im Folgenden näher dargestellt.

Intra- und intermediale Bezugnahme zwischen Kommunikaten

Die intramediale Bezugnahme bezeichnet ein Transkriptionsverhältnis zwischen Kommunikaten derselben Mediengattung. Prototypisch hierfür sind metakommunikative Prozesse bei der mündlichen Rede, wie sie bei der interaktiven Klärung missverständlicher Ausdrücke vorliegen. Die Transkription nutzt dabei die „eigentümliche Doppelstruktur“ [Hab95] der Sprache, „nämlich ihre Eigenschaft (...), mit Sprache über Sprache zu kommunizieren“ [jag04a]. Paraphrasen, Kommentare, Explikationen und Korrekturen sind Beispiele dafür, wie die Transkription die Linearität der gesprochenen Rede unterbricht, um Redesequenzen stillzustellen und autorekursiv zu bearbeiten.

Die intermediale Bezugnahme hingegen ist ein Verfahren, bei dem ein Medium durch ein andersartiges zweites Medium transkribiert wird [jag04a]. Dies liegt bei allen Formen der Bild-Text-Beziehungen, der Bild-Text-Musik-Beziehungen etwa im Film oder multimediale Kopplungen in Hypermedien vor. Besonders bedeutsam sind jedoch solche Transkriptionen, bei denen das abgeleitete Kommunikat das Original zum Zwecke der besseren Verständlichkeit ersetzen soll, wie das Aufklärungsvideo als Ersatz für den wissenschaftlichen Fachartikel. Häufig ist dies der Fall, wenn Rezipienten durch den bisher im Transfer eingesetzten Medientyp zwar kommunikativ erreicht, aber nicht spezifisch adressiert werden.

Adressierung der Semantik

Im Zuge der Dispersion des Wissens haben sich nicht nur Wissensgebiete und Sprachspiele ausdifferenziert, sondern auch gleichsam die gesellschaftlichen Adressenordnungen [Jäg06]. Die Adresse eines Rezipienten konstituiert sich aus seinem bisher vorhandenen Hintergrundwissen und seinen Erfahrungen im Umgang mit unterschiedlichen Transfermethoden. Rezipienten stellen in spezifischen Situationen jeweils spezifische Ansprüche an die Adressierung bzw. die Lesbarkeit von Kommunikaten. Ärzte sind gewohnt, ihr Wissen über medizinische Fachartikel zu beziehen. Zur Darstellung komplexer medizinischer Sachverhalte gegenüber fachfremden Transferpartnern können jedoch filmische Darstellungen oft besser geeignet sein.

Die Transkription nutzt dabei die mit unterschiedlichen Transfermethoden verbundenen Adressenoptionen, um die Kommunikate mit einem situationsadäquaten „Gebrauchssinn“ [jag04a] auszustatten, ohne den ihre Adressierung nicht gelingen kann. Transkriptionen können also im Zuge der Bearbeitung von Kommunikationsstörungen Informationen mit Adressierungsdefekten umadressieren oder nachjustieren. Sie können die in Kommunikaten (im Hinblick auf eine bestimmte Adressenordnung) eingeschriebene Unlesbarkeit in den Modus der Lesbarkeit überführen. Ein mehr oder weniger identisches Wissen wird also für eine bestimmte Zielgruppe so aufbereitet, dass diese es leichter rezipieren kann, wie es im Falle des RSI-Syndroms beschrieben wurde.

Evidenzauszeichnung des Sinns

Die Semantisierung eines lesbaren Kommunikats kann erst dann zu Wissen führen, wenn seine Semantik, wie gerade beschrieben, mit Sinn ausgestattet wird und dem Individuum daraufhin evident erscheint, d. h. in einem „subjektiven mentalen Zustand unmittelbarer Gewissheit“ [Jäg06]. Treffen jedoch Vertreter differierender Sprachspiele aufeinander, können unbekannte oder ungewohnte Wort- bzw. Zeichenverwendungen oder Formulierungsweisen eine kommunikative Störung auslösen. In solchen Fällen muss die Evidenz der zu übermittelnden Semantik im Zuge einer interaktiv-transkriptiven Störungsbearbeitung durch Erklärung, Argumentation oder Beweis diskursiv entwickelt werden. Während eine filmische Darstellung einer RSI-Kampagne aus sich heraus „überzeugend“ wirken kann, bedarf es bei einer mündlichen Erläuterung meist stärkerer rhetorischer Bemühungen zur Veränderung des Verhaltens.

4.2 Das Potenzial der interaktiven Störungsbearbeitung

Kommunikative Störungen verlieren im Lichte der Transkriptionstheorie ihren destruierenden Charakter, da die anschließenden Störungsbearbeitungen (Repairs) über die korrektive Funktion eine bedeutsame konstruktive Funktion für das Wissen aufweisen. Die bewusst oder unbewusste, interaktive oder selbstreferentielle Klärung von Missverständnissen erscheint als Prozess, der zwar oberflächlich gesehen das Verstehen eines Kommunikates verzögert, aber den Transfer des Wissens unter genauerer Betrachtung überhaupt erst ermöglicht.

Folgt man Jägers Auffassung der Störung als Ausgangspunkt transkriptiver Prozesse, lassen sich diese als Katalysatoren der Explikation impliziten Wissens beschreiben [Jäg04b]: Wissen wird im Zustand medialer Transparenz als stilles Wissen implizit prozessiert. Der Mediziner hat eine Komplexe Vorstellung des Repetitive Strain Injury Syndroms, welche er hinter diesem Ausdruck verbirgt. Sobald aber dieses implizite Wissen problematisch bzw. gestört wird, bedarf es der Explikation des Wissens in Repairhandlungen. Der Mediziner wird gebeten, zu erklären, was er mit dem Ausdruck RSI meint. Das stille Wissen wird dabei explizit, um die Störung zu beheben, und wird wieder unsichtbar, sobald dies gelungen ist.

Diese Wechsel zwischen dem impliziten und expliziten Zustand dürfen aber nicht als zwei Erscheinungsformen desselben Wissens gedeutet werden. Das Wissen mag zwar hinsichtlich der erzielten Verhaltensänderung ähnlich sein, aber niemals identisch. Hierin zeigt sich deutlich die konstruktivistische Färbung der Transkriptionstheorie. Die Semantik des explizierten Wissens hängt maßgeblich von den Möglichkeiten ab, es zu explizieren, weshalb Polanyi betont, „daß wir mehr wissen, als wir zu sagen wissen“ [Pol85] (Hervorhebung aus Original entfernt). Die Wahl des Mediums und die Kompetenz im Umgang mit einer Transfermethode schränken ein und konstituieren das, was wir ausdrücken können. Ein medizinischer Fachartikel zur Prävention von RSI könnte bei der Darstellung richtiger und falscher Handstellungen niemals die darstellerische Präzision eines Videofilmes erreichen. Das Medium ist als „Explikator des Impliziten“ [Jäg04b] stets mehr als ein bloßer Übermittler. Jeder transkriptive Prozess ist mit semantischen Effekten verbunden, so dass die explizierte Semantik, sobald sie wieder stilles Wissen wird, „in keinem analytischen Verhältnis“ zum ursprünglich explizierten stillen Wissen steht: „Im semantischen Netz hat eine Verschiebung stattgefunden“ [Jäg04b]. Man kann also mit Recht behaupten, dass in Folge der Störung bzw. in Folge der Explikation des impliziten Wissens, neues Wissen entstanden ist und beiden Transferpartnern zugänglich wurde. Das Wissen, dass vom Videofilm abgleitet werden kann, wird niemals identisch sein, mit dem Wissen, dass der Produktion des Videofilmes zugrunde lag.

Genau diese transkriptive Umwandlung sehen auch [NT97] als entscheidenden Prozess für die Genese von Wissen an. Sie unterscheiden insgesamt vier mögliche Transformationsprozesse zwischen implizitem und explizitem Wissen [NT97]. Die durch Störung bedingte Umwandlung von explizitem in implizites Wissen bezeichnen sie als „Externalisierung“, welche als einzige Transformation die Bildung konzeptuellen Wissens bewirken kann.

> Der wesentliche Prozeß der Wissensschaffung findet statt, wenn implizites in explizites Wissen umgewandelt wird – das heißt, wenn unsere Ahnungen, Wahrnehmungen, Denkmuster, Vorstellungen und Erfahrungen in etwas Mittelbares transformiert und in systematischer Sprache ausgedrückt werden [NT97]

Ein Transferpartner erhält also Wissen über einen Sachverhalt, indem zunächst während des störungsindizierten Repairhandelns Wissen über die Verwendung von

Zeichen und die Formulierung von Aussagen expliziert wird. Wird dieses explizierte Wissen verstanden bzw. internalisiert, steht es als implizites Wissen für das Verstehen der thematisierten Wörter wie z. B. für das Verstehen des Ausdrucks „Repetitive Strain Injury Syndrom“ zur Verfügung, sobald ein Arzt diesen Ausdruck gegenüber einem Praxisexperten verwendet. Wie dargelegt, unterscheidet sich dieses implizite Wissen prinzipiell von dem dem Explikationsprozess vorausliegenden impliziten Wissen über die Semantik der Wörter bzw. Aussagen. Beide Transferpartner bringen bei der Klärung irritierender Kommunikate jeweils ihr eigenes Hintergrundwissen mit ein, um dem Kommunikat eine für beide genuin neue Semantik zuzusprechen, die weder mit der ursprünglich assoziierten Semantik des Transferinitiators, noch mit der des Rezipienten identisch ist. Die Transferpartner bilden gemeinsam schrittweise ein neues Meta-Sprachspiel, das sich nicht auf den gemeinsamer Nenner der ursprünglichen Expertensprachspiele zurückführen lässt. Es handelt sich viel mehr um ein genuin neues Sprachspiel, das spezifisch zwischen zwei bestimmten Expertensprachspielen vermitteln kann, da es auf gemeinsam erarbeitetem und daher beidseitig geteiltem Hintergrundwissen beruht. Dies lässt sich am Ausdruck „Netzwerk“ verdeutlichen, den Soziologen oder Informatiker fachintern unterschiedlich verwenden würden. Die Vertreter beider Disziplinen würden so lange über die Bedeutung des Ausdrucks „Netzwerk“ diskutieren, bis jeder weiß was der andere meint, wenn er von Netzwerken spricht. Niemand würde dabei seinen eigenen Begriff aufgeben, sondern diesen vielmehr erweitern um eine neue Perspektive im Kontext der Informatik bzw. der Soziologie. Im Laufe kontinuierlicher Interaktion und ständiger iterativer Prozesse der Aushandlung von Ausdrucks-Semantiken bilden die Transferpartner ein Meta-Sprachspiel, mit Hilfe dessen sie zwischen ihren spezifischen Expertensprachspielen vermitteln können. Jeder Verwendung kritischer Ausdrücke läge stets die Perspektive des Gegenübers zugrund, was bei beiden eine Verwendungsweise evozieren soll, die für die Angehörigen der jeweiligen Expertengruppen verständlich ist.

5 Über die (Un-)Möglichkeit von Wissenstransfer

Folgt man diesen Überlegungen Jägers, besteht keinerlei Begründung mehr, um von ‚Transfer‘ von Wissen zu sprechen. Letztlich ist der Rezipient allein verantwortlich für die Semantisierung von symbolischen Strukturen im Zuge der „heterorhetorischen Zuende-Konstruktion der Alter-Äußerung“ [Jäg04b]. Es findet gegenüber herkömmlichen Semantikmodellen ein Rollenwechsel statt, bei dem der Absender seine transfer-ergebnis-determinierende Macht verliert. Der Rezipient emanzipiert sich von seiner bloß zeichenrezipierenden Rolle und wird zum aktiven Konstrukteur der Zeichenbedeutung bzw. des Ausdrucks. „Was in einem Gespräch ausgetauscht wird, sind nicht Gedanken, sind auch nicht Informationen, sind lediglich Wörter und Texte. Diese assoziiert jeder für sich mit Vorstellungen“ [Sch99b]. Der Kodierungs- und Dekodierungsprozess sollte also nicht verstanden werden, als wären In- und Output identisch. Wissen wird beim Transfer vollständig (re-)konstruiert, d. h. das Transferwissen des Rezipienten hat materialiter nichts mehr mit dem Transferwissen des Transferinitiators gemein. Gemäß der konstruktivistischen Denkweise Jägers kann der Transferinitiator dem Transferpartner nur Wissensangebote machen. Er kann das Wissen so „verpacken“, dass der Rezipient es sich mit höherer Wahrscheinlichkeit in der erwünschten Weise aneignet. „Transfer von Wissen ist aus streng konstruktivistischer Sicht nicht möglich“ [Sch05]. Dem Zielakteur wird kein altes Wissen ‚aufgedrängt‘, sondern er erschafft eigenständig neues Wissen durch inferentielle Bezugnahme auf sein sedimentiertes Hintergrundwissen über frühere Zeichenverwendungen; Wissen wird nicht transferiert sondern inferiert. Damit „muß der Empfänger einer sprachlichen Äußerung deren Bedeutung aus den konzeptuellen Elementen aufbauen, über die er schon verfügt“ [Sch99a]. „‚Wissenstransfer‘ ist somit eher eine Transformation bestehender Wissensbestände der Handlungspartner als eine Übertragung von für das Individuum neuen Erkenntnissen“ [Pal01]. Der Transferinitiator initiiert zwar den Transferprozess, die tatsächliche Vermittlung findet jedoch dann statt, wenn der Transferpartner das Wissen für sich selbst konstruiert und somit produziert. Prozesse der Produktion und Vermittlung von Wissen könnten aus streng konstruktivistischer Sichtweise auf einen einzigen Prozess der selbstreferentiellen Wissensaneignung durch den Rezipienten reduziert werden.

Um genau zu sein, müssten beim Transfer sogar zwei Prozesse der Produktion und Vermittlung von Wissen unterstellt werden: der Transferinitiator produziert neues Wissen, welches er sich während der Rezeption des Geäußerten unbewusst selbst vermittelt, genauso wie er es dem Rezipienten in Form seines geäußerten Kommunikates zur Verfügung stellt, der auf dieser Basis ein ähnliches Wissen generiert und sich ebenfalls selbst vermittelt. Soll nun der Erfolg des Wissenstransfers an der Ähnlichkeit zwischen dem ursprünglichen Wissen des Transferinitiators und dem angeeigneten Wissen des Rezipienten gemessen werden, erscheint der Wissenstransfer in der direkten Interaktion als optimale Voraussetzung. Der vermittelte – also nicht-interaktive – Transfer über Speichermedien wie die Schrift, beraubt die Transferpartner ihrer Möglichkeit zur direkten Erfolgskontrolle und Ergebniskorrektur und erschwert somit das Verstehen [Luh90]. Der Erfolg einer RSI-Kampagne kann nur schwer über das Medium der Schriftlichkeit gesichert werden. Den betroffenen Berufsgruppen sollte in diesem Beispiel die Gelegenheit gegeben werden Verständnisprobleme aufgrund irritierender Ausdrücke und Formulierungsweisen zeitnah zu klären, um ihnen das Sprachspiel und damit das dahinter verborgene Wissen zugänglich zu machen. Ob das Wissen zur Vermeidung von RSI richtig verstanden wurde, kann am besten im direkten Gespräch im Zuge der gemeinsamen Klärung missverständlicher Ausdrucksweisen geklärt werden, so dass sich eine grundsätzliche Korrelation zwischen dem Grad der Interaktion zweier Transferpartner und dem gegenseitigen Verstehen vermuten lässt.

Als kritisches Moment für erfolgreichen Transfer erscheint daher die interaktiv-transkriptive Störungsbearbeitung. Maßnahmen zur Verminderung der Transferproblematik sollten das Potenzial gemeinsamer Repairhandlungen ausschöpfen, während derer Wissen angeeignet und die Sprach(spiel)barrieren zwischen modularisierten Expertenwissensgebieten überwunden werden können.

6 Schlussfolgerungen aus der Transkriptionstheorie

Im Sinne der Transkriptionstheorie, welche Jäger als operative Antwort auf die Dispersion des Wissens versteht [jag08], konnte das Metaprojekt StArG verschiedene Potenziale zur Optimierung des Wissenstransfers zwischen Forschern und Praktikern im Präventiven Arbeits- und Gesundheitsschutz aufdecken. Die übergeordnete Strategie zielt auf die Integration der Forschung in die unternehmerische Praxis ab, so dass während der direkten Interaktion möglichst häufig Gelegenheiten zur transkriptiven Störungsbearbeitung gegeben und gemeinsame Sprachspiele gebildet werden. Im Folgenden sollen praktische Lösungswege aufgezeigt werden, die das Metaprojekt StArG aus der transkriptionstheoretischen Perspektive auf die Transferproblematik ableiten konnte.

Entwicklung und Zugänglichkeit von Metawissen

Die Komplexität des Wissens führt zum Retrieval-Problem, der steigenden Unfähigkeit relevantes Wissen zeitnah zu identifizieren. Das Metaprojekt StArG bietet mit dem Online-Portal, der interaktiven Diskussions- und Arbeitsplattform (iDA), einen für alle Akteure des Förderschwerpunktes ubiquitär erreichbaren Raum für Metawissen. Die Navigation ist dabei analog zur Struktur des Förderschwerpunktes angelegt, denn gemäß Ashbys „law of requisite variety" [Ash56] kann iDA als System nur Dank dieser Isomorphie die Komplexität des Systems des Förderschwerpunktes reduzieren. Jedem wissensproduzierenden Experten ist ein Ablageplatz für Kommunikate zugeordnet und seinem Projekt bzw. der Fokusgruppe untergeordnet. Der Isomorphismus birgt den Vorteil, sofern das Wissen über die Struktur des Förderschwerpunktes vorhanden ist, gezielt navigieren und Kommunikate abspeichern oder auffinden zu können.

Auswahl interaktiver Transfermethoden

Direkte Interaktion wird durch die Transkriptionstheorie als effizienteste und effektivste Strategie für die Bildung gemeinsamer Sprachspiele und den Transfer von Wissen ausgewiesen, da nur dort das volle Potenzial der Störungsbearbeitung ausgeschöpft werden kann. Zur Identifizierung möglichst interaktiver Transfermethoden bietet StArG ein Transfermittelportfolio, in dem ca. 60 für den Präventiven Arbeits- und Gesundheitsschutz relevante Transfermethoden hinsichtlich ihrer Interaktivität eingestuft wurden. Dieses Transfermittelportfolio steht allen Akteuren des Förderscherpunktes zur Verfügung und stellt die Basis für die methodische Vorbereitung und Durchführung von Veranstaltungen des Förderschwerpunktes, die durch das Metaprojekt StArG ausgerichtet wurden und werden, dar.

Auswahl der für den Rezipienten lesbarsten Transfermethoden

Für die Semantisierung von Kommunikaten wurde die rezipientenspezifische Lesbarkeit des Mediums als kritischer Faktor erkannt. Das Projekt StArG bietet Transferberatungen an, die im Rahmen von Transferdiagnoseworkshops und durch den Einsatz des StArG-Strategie-planers gezielt nach den vermuteten Medienpräferenzen bzw. Lesbarkeitsansprüchen des Rezipienten fragt. Der Strategieplaner ermittelt auf Basis der erhobenen Vermutungen über die Rahmenbedingungen des Rezipienten, die (wahrscheinlich) lesbarste Transfermethode aus dem Pool des Transfermittelportfolios.

Gemeinsames Erstellen von Kommunikaten

Wenn Forschungsexperten isoliert Kommunikate für Praxisexperten produzieren, besteht die Gefahr, dass der Wissenstransfer aufgrund einer partiellen Unvereinbarkeit der verwendeten Expertensprachspiele scheitert [LH09a]. Eine gemeinsame interaktive Produktion von Kommunikaten fördert die Bildung eines zwischen diesen Gebieten vermittelnden Meta-Sprachspiels. Höhepunkt der dritten Jahrestagung des Förderschwerpunktes Präventiver Arbeits- und Gesundheitsschutz war die gemeinschaftliche Verabschiedung des Aachener Impulses, einem Positionspapier, in dem die bisherigen Ergebnisse und zukünftigen Forschungsbedarfe des Präventiven Arbeits- und Gesundheitsschutzes – sowohl aus Sicht der Forschung, als auch aus Sicht weiterer Akteure und Stakeholder – zusammengefasst wurden. Um ein für alle Beteiligte verständliches und konsensfähiges Impulspapier zu erstellen, wählte das Metaprojekt StArG eine möglichst interaktive Methodik aus, die permanente Gelegenheiten zur interaktiven Störungsbearbeitung und Sprachspielbildung bot. Für den Aachener Impuls wurden zunächst innerhalb der thematisch unterschiedlichen Fokusgruppen im Rahmen offener Diskussionen Textbausteine gemeinschaftlich produziert. Dies trug zur Bildung eines Meta-Sprachspiels innerhalb der Fokusgruppen bei. Die erarbeiteten Textbausteine wurden durch ein Redaktionsteam, in dem Vertreter der Fokusgruppen (und damit aller Meta-Sprachspiele) versammelt waren, verknüpft und für die endgültige Verabschiedung im Plenum vorbereitet. Die Diskussion in Dialogforen und im Plenum trug zur Bildung eines Meta-Sprachspiels höherer Ordnung bei, welches allen Projektpartnern und anwesenden Akteuren des Präventiven Arbeits- und Gesundheitsschutzes zugänglich war und zur Verabschiedung eines vom gesamten Förderschwerpunkt getragenen Aachener Impulses als gemeinsames Kommunikat führte.

Die Experten-Rollen im Produktionsprozess

Die Ergebnisse des Metaprojektes StArG zeigen den transferförderlichen Einfluss langfristig angelegter Transferpartnerschaften zwischen Forschung und Praxis. Entscheidender als der Einsatz interaktiver Transfermethoden ist vielmehr noch die gegenseitige Anerkennung der Forscher und Praktiker als gleichberechtigte Experten innerhalb der Projektarbeit. Dabei ist zu „reflektieren, dass nicht bloß [...] die Wissenschaft in ein System der Praxis, sondern auch das System der Praxis in die Wissenschaft hinein interveniert“ [HSS09]. Demnach sind Kommunikations- und Kooperationsräume in der Projektarbeit zu schaffen, die die Expertise von Forschern und Praktikern gleichsam in den gemeinsamen Entwicklungsprozess einfließen lassen, um so einen Mehrwert für beide Seiten zu schaffen [Val09]. Um die Effizienz und Effektivität der Projektarbeit zu steigern, sollten die komplementären Expertenwissensgebiete frühest möglich allen Projektpartnern zugänglich gemacht werden. Daher empfiehlt sich eine Integration der Praxispartner in den Produktionsprozess des Wissens (Forschung) schon bei der gemeinsamen Antragstellung, so dass sich die Grenzen zwischen Wissensproduzent und -rezipient – und damit zwischen Produktion und Vermittlung – zu Gunsten einer gleichberechtigten Transferpartnerschaft verringern. Dies setzt eine Abkehr von einem Sender-Empfänger-Denken bei der „Transfer"-Arbeit voraus [LH09b]: es geht nicht um die isolierte Lösungssuche von Forschung für die unternehmerische Praxis mit einem universellen Umsetzungsanspruch. Vielmehr muss die Spezifik unternehmerischer Notwendigkeiten und Rahmenbedingungen sowie das Erkenntnisinteresse von Forschung gleichberechtigt in der kooperativen Projektarbeit berücksichtig werden.

7 Zusammenfassung

Das Transferproblem des Präventiven Arbeits- und Gesundheitsschutzes erweist sich als spezifische Symptomatik eines universellen Transferproblems der Produktion und Vermittlung von Wissen, bedingt durch eine Komplexitätssteigerung des Wissens und der Sprachspiele im Zuge der Leistungssteigerung des Wissenschaftssystems. Die Transkriptionstheorie hilft dabei, weitestgehend unbemerkte Verbesserungspotenziale für den Wissenstransfer im Präventiven Arbeits- und Gesundheitsschutz zu identifizieren, die auf die Kompensierung der Sprachbarrieren zwischen modularisierten Wissensgebieten abzielen. Ausgangspunkt ist die Erkenntnis, dass bei der partnerschaftlichen Bearbeitung kommunikativer Störungen Wissen simultan produziert und vermittelt wird und gemeinsame Meta-Sprachspiele gebildet werden, die wiederum die Erfolgswahrscheinlichkeit des Transfers erhöhen. Zur Ausschöpfung des Störungspotenzials sollten daher möglichst häufig Gelegenheiten zu deren interaktiv-transkriptiven Bearbeitung geboten werden. Eine Strategie zur Erreichung dieses Ziels ist die konsequente Integration der Forschung in die Praxis zum Zwecke der gemeinschaftlichen Produktion von für beide Seiten verständlichen Wissens.

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Strategien und Merkmale der Innovationsfähigkeit von kleinen und mittleren Unternehmen

Alan Hansen, Sven Trantow, Anja Richert, Sabina Jeschke

Zusammenfassung Bereits seit einigen Jahren wird die Bedeutung von Innovationen für das Wachstum und den nachhaltigen Erfolg von Unternehmen sowohl in der Wissenschaft als auch der Politik intensiv diskutiert. Insbesondere der steigende Wettbewerbsdruck sowie sich ständig wandelnde Marktbedingungen und Kundenanforderungen stellen sicher, dass langfristig nur solche Unternehmen Erfolg haben, die die Wichtigkeit von Innovationsfähigkeit für den Unternehmenserfolg erkannt haben. Daher ist intensive Forschung über die organisationalen Rahmenbedingungen und Faktoren, welche die Innovationsfähigkeit und den Innovationserfolg von Unternehmen ausmachen, unabdingbar. Seit 2007 untersucht das vom BMBF geförderte und vom IMA/ZLW & IfU der RWTH Aachen durchgeführte transdisziplinäre Forschungsprojekt International Monitoring (IMO) das Thema Innovationsfähigkeit und seine wissenschaftliche, politische und insbesondere ökonomische Bedeutung für Deutschland und Europa. Zu diesem Zweck werden unter anderem regelmäßig Innovationsworkshops in kleinen und mittleren Unternehmen (KMU) durchgeführt, die darauf abzielen, Strategien und Strukturmerkmale von Innovationsfähigkeit zu identifizieren. Während dieser Workshops analysiert das Projekt IMO die Innovationsprozesse von Unternehmen und forscht zudem nach Potentialen für eine innovationsfreundliche Gestaltung von Arbeits- und Lernprozessen sowie Arbeitsumgebungen, um die Innovationsfähigkeit der Unternehmen zu verbessern. Dieser Artikel stellt die aktuellen Diskussionen des Forschungsfelds Innovationsfähigkeit aus der Perspektive der Personal-, Organisations- und Kompetenzentwicklung dar. Dazu werden relevante Forschungsergebnisse aus qualitativen Unternehmensanalysen vorgestellt. Insgesamt skizziert der Artikel neun identifizierte Strategien sowie 35 abgeleitete organisationale Gestaltungsmerkmale, durch welche Unternehmen ihre Innovationsfähigkeit systematisch steigern können. Dies geschieht vor allem durch die Implementierung organisationaler Rahmenbedingungen, die einerseits die Generierung von Innovationen fördern und andererseits dazu

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beitragen, eine Innovationskultur im Unternehmen etablieren. Außerdem werden aktuelle Problemfelder und bisher ungenutzte Innovationspotentiale in Unternehmen beschrieben.

Schlüsselwörter: Innovationsfähigkeit, KMU, Strukturmerkmale

1 Relevanz von Innovationsfähigkeit für KMU im Wirtschaftsraum Deutschland

Innovation ist einer der zentralen Aspekte in der Diskussion um die zukünftige Wettbewerbsfähigkeit von Hochlohnländern wie Deutschland [KSDW06]. Innovationen gelten dabei als Schlüsselfaktoren, um den komplexen und dynamischen Veränderungen der heutigen Arbeits- und Lebenswelt erfolgreich begegnen zu können. Neuerungen können dabei in unterschiedlichen Bereichen erfolgen. Im Produktbereich- und Prozessbereich werden vor allem neue oder verbesserte Produkte, Dienstleistungen oder Fertigungs- und Verfahrenstechniken auf den Markt gebracht [HBR06]. In der Innovationsforschung werden neben diesen technischen Innovationen aktuell auch soziale und organisationale Innovationen vermehrt thematisiert. Sie beziehen sich auf den Prozess der Entstehung, Durchsetzung und Verbreitung von neuen sozialen und organisationalen Praktiken [HJ10]. Soziale und organisationale Innovationen sind folgenreiche, vom gewohnten Schema abweichende Regelungen von Tätigkeiten und Vorgehensweisen [Gil00]. Insbesondere in kleinen und mittleren Unternehmen werden Innovation und Entwicklung zunehmend in den Bereichen Beratung, Informationsverarbeitung, Forschung und Anwendung vorangetrieben [Mey05].

Die Wettbewerbsfähigkeit von Unternehmen hängt vor allem davon ab, wie schnell neue Produkte und Dienstleistungen auf den Markt gebracht und neue, kostensparende Verbesserungen und Prozesse eingeführt werden [Kom00]. Die Überlebensfähigkeit eines Unternehmens basiert demnach mehr und mehr auf der Fähigkeit. Die unternehmerische Steigerung der Innovationsfähigkeit avanciert vor diesem Hintergrund zu einem der bedeutendsten organisationalen Strategien bei der Sicherung der Wettbewerbsfähigkeit und letztlich auch der Unternehmensexistenz [Bus05]. Nichtsdestotrotz besteht ein erheblicher Forschungsbedarf insbesondere in Bezug auf eine ganzheitliche Sichtweise auf Innovationen, die den Menschen sowie die organisationalen Rahmen- und Arbeitsbedingungen als integralen Bestandteil mit einbezieht.

Die Fähigkeit, Innovationen hervorzubringen wird häufig als mehrdimensionales Konstrukt verstanden [Sch09] und als ein die Gesamtorganisation umspannendes Phänomen charakterisiert [Sam06]:

> [...] innovativeness is not one-dimensional but needs to be described and operationalised along multiple dimensions. These are market- and technology-related changes, organizational changes and environmental alternations. [Koc07]

Um sich dem Phänomen Innovationsfähigkeit zu nähern, wird vielfach eine Unterscheidung in eine organisationale und eine personale Dimension vorgenommen

[The06]. Innovationsfähigkeit meint damit nicht nur die Fähigkeit eines Unternehmens, Innovationen hervorzubringen, sondern ist vor allem auch an den Menschen mit seinem Können und seinem Wissen gebunden [Dis05]. Innovationsfähigkeit ist somit von intra- und interpersonellen Faktoren und von Ausprägungen des Arbeitssystems – damit sind Arbeitsorganisation, Unternehmenskultur, Führung etc. gemeint – abhängig [Win07]. Sie kann folglich als „ability of an enterprise's employees to generate ideas and to work with these ideas to develop new or improved products, services, technologies, work processes or markets" [DJKS01] definiert werden. Die Antwort auf die Frage, wie die Innovationsfähigkeit innerhalb eines Unternehmens gesteigert werden kann, liegt in der Ausgestaltung innovationsförderlicher technischer und organisationaler Rahmenbedingungen, die zur Aktivierung des Mitarbeiter- und somit auch des Humanpotentials beitragen. Vor allem in kleinen und mittelständischen Unternehmen ist es wichtig, alle personellen und immateriellen Innovationspotentiale in optimaler Weise zu nutzen und in Innovationen umzuwandeln, da KMU häufig mit größenbedingten Ressourceneinschränkungen (Kapitalausstattung, strategische Unternehmensentwicklung, Bandbreite an Qualifikationen und Kompetenzen der Mitarbeiter, Vernetzung nach außen, systematische Marktbeobachtung, etc.) zu kämpfen haben [KSDW06]. Im Gegensatz zu Großunternehmen sind die Aufwendungen für Innovationsprojekte in KMU geringer. Aus diesem Grund scheinen kleinere Unternehmen tendenziell weniger innovativ zu sein als große Unternehmen. Diese Tatsache ist darauf zurückzuführen, dass es in KMU größerer Innovationsanstrengungen bedarf, um trotz der Ressourceneinschränkungen innovativ zu sein. Darüber hinaus sind KMU am Wirtschaftsstandort Deutschland gegenüber Großunternehmen stärker von dem drohenden Fachkräftemangel betroffen, da sie bei Berufseinsteigern häufig als weniger attraktiv eingestuft werden. Gründe dafür sind u. a. geringere Gehälter und wenig finanzieller Spielraum für innovative Aktivitäten [Ver07].

Die Innovationsfähigkeit von KMU wird aus diesem Grund einerseits entscheidend davon beeinflusst, wie effizient größenspezifische Vorteile (höhere interne Vernetzung der Mitarbeiter, kürzere Entscheidungswege, etc.) genutzt werden können und wie andererseits mit den Nachteilen der geringeren Ressourcenausstattung umgegangen wird. Vor diesem Hintergrund ist es für Entscheidungsträger in KMU essentiell, die wichtigsten organisationalen Gestaltungsmerkmale zur Stärkung der Innovationsfähigkeit zu kennen und diese bedarfsgerecht in die prozessualen Abläufe und strukturellen Gegebenheiten des Unternehmens zu integrieren.

2 Das Projekt International Monitoring: Strategien zum Umgang mit den zentralen Dilemmata wirtschaftlichen Handelns

Im Rahmen des Forschungs- und Entwicklungsprogramms „Arbeiten – Lernen – Kompetenzen entwickeln, Innovationsfähigkeit in einer modernen Arbeitswelt" fördert das deutsche Bundesministerium für Bildung und Forschung und der Europäische Sozialfonds für Deutschland eine Untersuchung von zentralen Dilemmata wirtschaftlichen Handelns, welche sich in der nationalen und internationalen Arbeitsentwicklung zunehmend aufbauen. Das am Institutscluster IMA/ZLW & IfU der RWTH Aachen durchgeführte Projekt „International Monitoring“ (IMO) identifiziert den Widerspruch zwischen Nachhaltigkeit und kurzfristiger Nutzenmaximierung als eines der grundlegendsten Probleme bei der Bewältigung von Managementaufgaben in profitorientierten Wirtschaftsbereichen. Das klassische Paradigma des Homo Oeconomicus zielt auf die (kurzfristige) Realisierung des größtmöglichen Nutzens, monetär bemessen also auf die Maximierung der eigenen Gewinne. Diese Maxime zwingt Wirtschaftssubjekte zu einem rücksichtslosen Handeln und ist mit einem vorausschauenden, verantwortlichen sowie dauerhaft erfolgreichen Management nicht vereinbar [Thi09]. Vor dem Hintergrund organisationaler Innovationsfähigkeit lässt sich dieser handlungsimmanente Widerspruch durch vier dialektische Spannungsfelder beschreiben, welche einerseits durch notwendige Voraussetzungen innovationsfähiger und nachhaltiger Unternehmen und andererseits durch unterschiedliche Dimensionen von ökonomischem Druck charakterisiert sind [HTH10]:

- Verantwortlicher Umgang mit Humanressourcen vs. Kostendruck
- Langfristige Strategien zur Erhöhung der Innovationsfähigkeit vs. Erfolgsdruck
- Zeit für Lernprozesse vs. Zeitdruck
- Stabilitätsbedarf vs. Flexibilisierungsdruck.

Mit Hilfe dieser vier interdependenten Dilemmata (Abb. 1) können eine Vielzahl der diffizilen sozioökonomischen Hindernisse und Herausforderungen auf dem Weg zur Stärkung und Manifestierung der organisationalen Innovationsfähigkeit kategorisiert werden.

Diese Dilemmata bilden, als Gegenstand der aktuellen und zukünftigen humanorientierten Innovationsforschung, wichtige Schwerpunkte. Das IMO-Projekt unterstützt die umfangreiche Forschungsarbeit des F&E-Programms mit einem kontinuierlichen internationalen Monitoring, bei dem die internen Forschungsergebnisse aller beteiligten Projekte und alle relevanten Informationen zum Thema Innovationsfähigkeit aus der nationalen und internationalen Forschung, Wirtschaft und Politik gesichtet, analysiert und verdichtet werden. Primäres Ziel des IMO-Projektes ist es, praktikable nationale und internationale Lösungsansätze und Strategien für die Ausbalancierung der Dilemmata zu identifizieren. Auf der ökonomischen Ebene sind KMU die Protagonisten für den Innovationserfolg am Wirtschaftsstandort Deutschland. Für diese Zielgruppe hat IMO zum aktuellen Zeitpunkt neun relevante Strategien zur „Steigerung der Innovationsfähigkeit“ identifiziert:

- Gesundheitsmanagement
- Etablierung von Innovationskulturen
- Nutzung von Wissen- und Humankapital
- Kontinuierliche Kompetenzentwicklung
- Ganzheitliches Innovationsmanagement
- Förderung sozialer und organisationaler Innovationen

Abb. 1 Zentrale Dilemmata wirtschaftlichen Handelns

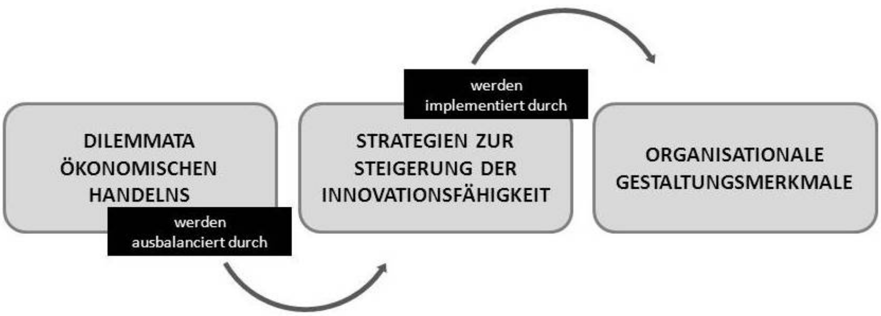

Abb. 2 Zusammenhang zwischen Dilemmata, Strategien und Gestaltungsmerkmalen

- Öffnung von Innovationsprozessen
- Innovative Formen der Arbeitsorganisation
- Management der Ungewissheit.

Bei den Strategien handelt es sich im Allgemeinen um steuerbare Verhaltensweisen der Unternehmen, die verschiedene innovationsförderliche Gestaltungsmerkmale aufweisen. Um die erforderlichen Gestaltungsmerkmale der einzelnen Strategien bestimmen zu können, wurden Innovationsworkshops mit KMU durchgeführt (Kap. 3). Der Zusammenhang zwischen Dilemmata, Strategien und Gestaltungsmerkmalen ist zusammenfassend in Abb. 2 illustriert.

3 Innovationsworkshop zur Bestimmung von innovationsförderlichen Strategien und Gestaltungsmerkmalen

Im Rahmen einer empirischen Datenerhebung wurden insgesamt 10 Innovationsworkshops mit deutschen KMU durchgeführt. Bei den untersuchten Unternehmen handelt es sich mehrheitlich um Organisationen mit bis zu 50 Mitarbeitern und einem Jahresumsatz von bis zu 500 Millionen Euro. Der Großteil der Unternehmen gehört den Branchen „Industrie/Verarbeitendes Gewerbe" sowie „Beratung/Sonstige Dienstleistungen" an. Die Auswahl der teilnehmenden Unternehmen orientierte sich an der Vergabe von Auszeichnungen für besonders innovatives Verhalten. So ermittelt z. B. die Studie „TOP 100" jährlich die innovativsten deutschen Mittelständler anhand einer Benchmark-Analyse der Kriterien innovationsförderndes Management, Innovationsklima, innovative Prozesse und Innovation, Innovationsmarketing und Innovationserfolg.

Um aussagekräftige Ergebnisse aus den Workshops zu erhalten, wurde ein Verfahren zur Unternehmensdiagnose als methodische Grundlage eingesetzt: das OSTO (offene, soziotechnische, ökonomische) Systemmodell basiert auf der OSTO-Systemtheorie, die komplexe Systeme und Organisationen als lebende Systeme versteht. Die dem Modell zugrunde liegende Annahme ist, dass sich ein bestimmtes Systemverhalten aus dem wechselseitigen Zusammenspiel verschiedener Gestaltungskomponenten (-merkmale) gibt [Hen]. Dieser Ansatz kann auf das Hervorbringen von Innovationen übertragen werden. Die Kenntnis über innovationsförderliche Gestaltungsmerkmale einer Organisation versetzt Entscheidungsträger demnach in die Lage, gezielt Einfluss auf Innovationsprozesse nehmen zu können. Auch Kutter geht davon aus, dass sich Innovationsfähigkeit aus dem proaktiven Gestalten und Beherrschen des stetigen Kreislaufs aus Verbesserungen und Erneuerungen ergibt [Kut07]. Unternehmen sind demnach gefordert, durch gezieltes Eingreifen in Organisationsprozesse Rahmenbedingungen zu schaffen, die innovatives Denken und Handeln ihrer Mitarbeiter fördern.

Das Herausfiltern relevanter Gestaltungsmerkmale sowie deren Zuordnung zu den bereits identifizierten innovationsförderlichen Strategien aus dem International Monitoring liefert somit einen strukturierten Überblick über eine breite Palette an Handlungsoptionen im Umgang mit den Dilemmata wirtschaftlichen Handelns. Darüber hinaus wurden die Ergebnisse an aktueller Forschungsliteratur gespiegelt und verifiziert. Die Ergebnisse der Auswertung werden im folgenden Kapitel vorgestellt.

Abb. 3 Gestaltungsmerkmale der Strategie „Gesundheitsmanagement“

4 Innovationsförderliche Strategien und Gestaltungsmerkmale

Nachdem die Methodik der Innovationsworkshops skizziert wurde, werden im Folgenden Strategien und Gestaltungsmerkmale vorgestellt, die Unternehmen einerseits für einen effizienten und langfristig erfolgreichen Umgang mit den im ersten Kapitel beschriebenen Dilemmata einsetzen und andererseits die unternehmerische Innovationsfähigkeit steigern können. In diesem Kontext werden relevante Erkenntnisse aus zehn analysierten Unternehmen bezüglich angewendeter innovationsförderlicher Strategien vorgestellt, die ihrerseits wiederum verschiedene Gestaltungsmerkmale aufweisen. Insgesamt wurden acht innovationsrelevante Strategien identifiziert, die im Folgenden einzeln beschrieben werden. Die entscheidenden Gestaltungsmerkmale zu jeder Strategie sind in der jeweils dazugehörigen Grafik aufgeführt.

4.1 Strategie 1: Gesundheitsmanagement

Unbestritten gehört ein betriebliches Gesundheitsmanagement zu den Eckpfeilern eines verantwortungsbewusst und nachhaltig sozial handelnden Unternehmens. Betriebliches Gesundheitsmanagement ist ein wichtiger Wettbewerbs- und Beschäftigungsfaktor, da es die Gesundheit, Zufriedenheit und Motivation der Mitarbeiter als strategische Faktoren in das Leitbild, die Kultur sowie die Strukturen und

Prozesse eines Unternehmens einbezieht [Wie02]. Neben verschiedenen betrieblichen Angeboten, die auf die Linderung körperlicher Beschwerden abzielen, müssen ebenso Angebote zur Behandlung psychischer Probleme, auf die viele langfristige gesundheitliche Probleme zurückzuführen sind, in das betriebliche Gesundheitsmanagement integriert werden. Auch die Etablierung und kontinuierliche Aufrechterhaltung der Balance zwischen Arbeits- und Privatleben (besser bekannt unter dem Schlagwort Work-Life-Balance) fällt in den Bereich des betrieblichen Gesundheitsmanagements.

Durch die konsequente Implementierung von präventiven, gesundheitserhaltenden und gesundheitsförderlichen Maßnahmen ergeben sich zahlreiche Vorteile für die Innovationsfähigkeit eines Unternehmens, da Mitarbeiter mit einer erhöhten Arbeitszufriedenheit und Motivation letztlich insgesamt eine höhere Produktivität und Leistungsbereitschaft und damit Innovationsfähigkeit aufweisen. Andererseits kann das Gesundheitsmanagement insofern als ein nachhaltiger Wettbewerbsfaktor angesehen werden, da qualifizierte Mitarbeiter im „War for Talents“ durch positive Imageeffekte leichter rekrutiert und langfristig im Unternehmen gehalten werden können [Bun05, FHS03].

4.2 Strategie 2: Etablierung von Innovationskulturen

Bei allen Versuchen und Maßnahmen, die Innovationsfähigkeit eines Unternehmens zu erhöhen, bleiben häufig die zugrunde liegenden, kulturellen Mechanismen eines Unternehmens unberücksichtigt. Dabei zeigen zahlreiche Beispiele unternehmerischen Handelns, dass eine Vernachlässigung der Innovationskultur schwerwiegende und kostenträchtige Folgen nach sich ziehen kann [Sch03]. Als Basis der Innovationsfähigkeit eines Unternehmens ist die Innovationskultur vielmehr „der stärkste Magnet, wenn es darum geht, die echten Talente und High Potentials zu gewinnen und zu halten.“ [JZ07]. Innovationskulturen werden dabei als Subkulturen der gesamten Unternehmenskultur beschrieben, die als spezifische Grundannahmen, Werthaltungen, Fähigkeiten und Normen bezeichnet werden, die sich auf das Bewältigen von Innovationsaufgaben beziehen und von den am Innovationsprozess Beteiligten geteilt werden [The06]. Innovationskulturen können vor diesem Hintergrund als Nährboden jedes innovativen Handelns angesehen werden. Hierbei wird davon ausgegangen, dass der Ursprung jeder unternehmerischen Leistung in der Begeisterungsfähigkeit der Mitarbeiter sowie der Leidenschaft, dem Engagement und der Glaubwürdigkeit der Führungsebene liegt [JZ07]. Die Innovationskraft eines Unternehmens wird demzufolge nicht nur von Entscheidungsträgern, sondern insbesondere auch von Mitarbeitern der mittleren und unteren Hierarchieebene entwickelt. Die Basis dafür muss bewusst und dauerhaft im Rahmen der Etablierung von Innovationskulturen gelegt werden.

Zur Etablierung von Innovationskulturen finden sich verschiedene Gestaltungsmerkmale in Unternehmen, die sowohl von der Führungsebene als auch von den Mitarbeitern selbst umgesetzt werden müssen. Beispielsweise ist eine effiziente und effektive Kommunikation zwischen den Organisationsmitgliedern zentraler Treiber

Abb. 4 Gestaltungsmerkmale der Strategie „Etablierung von Innovationskulturen"

einer innovationsförderlichen Kultur, da diese das Innovationsgeschehen im Unternehmen entscheidend fördert und verändert. Auch eine produktive Fehlerkultur ist Bestandteil einer Innovationskultur, da nur durch den toleranten und bewussten Umgang mit Fehlern Kreativität und Ideenreichtum gefördert werden kann.

4.3 Strategie 3: Nutzung von Wissen und Humanpotential

Neben materiellen und finanziellen Ressourcen ist Wissen einer der wichtigsten Faktoren für den Geschäftserfolg von Unternehmen. Im Zuge der Verschiebung von der Produktions- zur Dienstleistungs- und Wissensgesellschaft nehmen Wissen und Humanpotential im Vergleich zu traditionellen materiellen Ressourcen rasant an Wert zu und sind entscheidende Triebfedern von Innovationsprozessen [AHM05, SvdBH08, Sam06]. Der Mensch gewinnt dabei im Unternehmenskontext mit zunehmender Notwendigkeit der Fokussierung auf nachhaltige Wettbewerbsfaktoren an Bedeutung [SvdBH08]. Die systematische und zielgerichtete Nutzung vorhandener interner Humanressourcen sowie deren verantwortungsvolles Management sind daher zentrale Bezugspunkte einer nachhaltigen und innovationsförderlichen Unternehmensstrategie. Da das interne Wissen personengebunden ist und damit für Unternehmen eine knappe und fragile Ressource darstellt, wächst sowohl die Bedeutung der Sicherung und Strukturierung von Wissen als auch dessen Transfer.

Abb. 5 Gestaltungsmerkmale der Strategie „Nutzung von Wissen- und Humanpotential"

Diversity-Aspekten kommt bei der Frage nach der effizienten Nutzung von Wissen und Humankapital ebenfalls eine besondere Rolle zu, da sich die Wissensbasis eines Unternehmens durch eine möglichst große Vielfalt an Mitarbeiterpotentialen steigern lässt. Diversity steht aus unternehmerischer Sicht für die Integration von Menschen mit u. a. unterschiedlichem Alter, Geschlecht und Fähigkeiten und somit für eine Vielfalt von Mitarbeiterpotentialen [HD09]. Durch eine optimale Ausschöpfung des Kreativitätspotenzials aller Mitarbeiter sowie die Integration von Diversity-Aspekten in den Unternehmensalltag kann die Innovationsfähigkeit eines Unternehmens signifikant gesteigert werden. Diversität kann demzufolge als Ressource für Innovationsfähigkeit angesehen werden, da sie von der produktiven Vielfalt der Attribute der Mitglieder einer Organisation ausgeht und die Wissensbasis eines Unternehmens erweitert [DRLvS08].

4.4 Strategie 4: Kontinuierliche Kompetenzentwicklung

Da die Initiierung und Umsetzung von Innovationen keineswegs nur auf dem Wissen von Entscheidungsträgern und Spezialisten beruht, ist ein höherwertiges Lernen aller Mitarbeiter für die Innovations- und Zukunftsfähigkeit eines Unternehmens von großer Bedeutung. Hinzu kommt, dass Menschen in Zukunft länger arbeiten werden als je zuvor und im Laufe ihres Berufslebens heterogene Aufgaben übernehmen, die einen Prozess der kontinuierlichen und lebensbegleitenden Kompetenzentwicklung fordern und fördern [fH06].

Abb. 6 Gestaltungsmerkmale der Strategie „Kontinuierliche Kompetenzentwicklung"

Unternehmen müssen daher bei allen Beschäftigten einen Prozess der systematischen und lebenslangen Kompetenzentwicklung unterstützen [fH06]. Zusätzlich muss aufgrund des Ausscheidens älterer Mitarbeiter langjähriges Erfahrungswissen frühzeitig gesichert und an neue Mitarbeiter weitergegeben werden. An die Stelle der einmaligen Berufsqualifikation tritt deshalb ein lebenslanges Lernen im Prozess der Arbeit, durch welches das Wissen und die Fähigkeit dieses anzuwenden, ständig angepasst und erweitert werden können. Dabei geht es primär darum, die Kontextbedingungen in Unternehmen gemäß der identifizierten Gestaltungsmerkmale so einzurichten, dass sich die Wissensträger hinsichtlich des Erwerbs und der Weitergabe von Wissen möglichst frei entfalten können. Allerdings haben Lern- und Kompetenzentwicklungsmaßnahmen nur wenig Sinn, wenn das erworbene Wissen nicht unmittelbar am Arbeitsplatz angewendet und die berufliche Handlungskompetenz im Unternehmen trainiert werden kann. Arbeiten und Lernen müssen deshalb integral miteinander vernetzt werden. [PM06].

4.5 Strategie 5: Ganzheitliches Innovationsmanagement

Gutes Management ist bei Innovationen genauso relevant wie in allen anderen Bereichen der Unternehmensführung [EN07]. Aus diesem Grund hat das obere Mana-

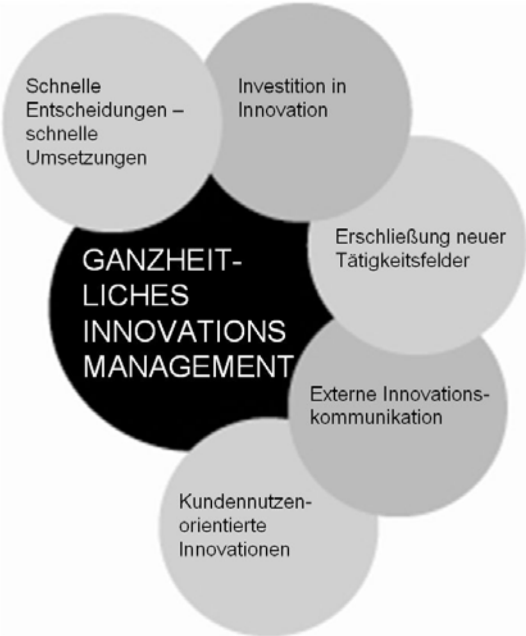

Abb. 7 Gestaltungsmerkmale der Strategie „Ganzheitliches Innovationsmanagement"

gement eine wichtige Führungsaufgabe für erfolgreiche Innovationsaktivitäten im Unternehmen. Damit Innovationen und Ideen im Unternehmen überhaupt entstehen können, müssen top-down die richtigen Stellschrauben gedreht werden. Nur, wenn die Führungsriege signalisiert, dass sie für Ideen und Kreativität offen ist und in Neuerungen investieren will, kann das Innovationspotential des gesamten Unternehmens ganzheitlich ausgeschöpft werden. Der Erfolg oder Misserfolg von Innovationsvorhaben hängt damit davon ab, welchen Stellenwert das Management dem Innovationsgeschehen tatsächlich beimisst [Pös].

Das Ergebnis eines gelungenen Innovationsmanagements liegt dabei in der erfolgreichen Platzierung von Produkten oder Dienstleistungen am Markt. Hieraus ergibt sich die wesentliche Aufgabe des Innovationsmanagements: die systematische Unterstützung des gesamten Innovationsprozesses von der Generierung neuer Ideen bis hin zur Umsetzung neuer Produkte, Dienstleistungen oder Prozesse [MD09]. Hierbei wird davon ausgegangen, dass das Innovationsmanagement die „dispositive Gestaltung von einzelnen Innovationsprozessen" [Hau97] zur Aufgabe hat. Darüber hinaus definiert das Innovationsmanagement Strategien und Ziele, trifft Entscheidungen, bestimmt Informationsflüsse, stellt soziale Beziehungen her und wirkt auf Personen ein, um Entscheidungen zu realisieren [Pös]. Wichtig für ein erfolgreiches Innovationsmanagement in Unternehmen ist, dass die Führungsebene Entscheidungen während des Innovationsprozesses schnell trifft und somit die schnelle Umsetzung von Innovationen unterstützt. Zusätzlich sollte das Management Bereitschaft signalisieren, in Innovationen zu investieren, d. h. z. B. finanzi-

Abb. 8 Gestaltungsmerkmale der Strategie „Öffnung von Innovationsprozessen"

elle Mittel für Innovationsvorhaben zur Verfügung zu stellen oder neue Mitarbeiter für Innovationsvorhaben einstellen.

4.6 *Strategie 6: Öffnung von Innovationsprozessen*

Unternehmen sind in Zeiten des steigenden Wettbewerbsdrucks zu immer kürzeren Innovationszyklen bei gleichzeitig sinkenden F&E-Budgets dazu gezwungen, ihre Innovationsprozesse zu öffnen, um durch die Einbeziehung externer Partner ihre Innovationsfähigkeit zu erhöhen [GE]. Innovationsaktivitäten vollziehen sich demnach nicht mehr nur im Unternehmen selbst, sondern müssen als interaktiver Prozess zwischen Unternehmen und Markt gesehen werden, dessen Ziel es ist, das kreative Potential unternehmensexterner Quellen ganzheitlich zu nutzen). Offene Innovationsprozesse gehen über die Grenzen von Unternehmen oder Abteilungen hinaus und binden verschiedene Akteure als Ideengeber, Konzeptentwickler und Innovationsumsetzer in die Gestaltung von Innovationen mit ein. Auf diese Weise können Innovationshemmnisse wie Kostendruck, fehlendes Risikokapital oder mangelndes innerorganisationales Humanpotential reduziert werden. Der Erfolg einer Innovation basiert folglich zu einem großen Anteil auf der Fähigkeit des Unternehmens, entlang aller Phasen des Innovationsprozesses Netzwerke mit externen Akteuren einzugehen [RP]. Als Kernprozesse werden der Outside-In, der Inside-Out und der Coupled-Prozess definiert. Dabei reichert der Outside-In-Prozess das in-

Abb. 9 Gestaltungsmerkmale der Strategie „Innovative Formen der Arbeitsorganisation"

terne Wissen des Unternehmens mit externem Wissen von Kunden, Lieferanten und Partnern an. Hierzu zählen auch das aktive Transferieren von Technologien und Prozessen aus anderen Unternehmen und Universitäten. Der Inside-Out-Prozess hingegen unterstützt Kommerzialisierung, wobei durch Lizensierung vorhandene Ideen rascher auf den Markt und Technologien besser multipliziert werden können. Der Coupled-Prozess beinhaltet eine Kopplung der Integration und Externalisierung von Wissen zum Zweck der gemeinsamen Entwicklung, bei der eine Balance zwischen Geben und Nehmen den Kooperationserfolg bestimmt [GE06]. Eine wichtige Aufgabe im Zusammenhang mit der Öffnung von Innovationsprozessen besteht in der Aus- und Weiterbildung von Unternehmens- und Kundenkompetenzen. In diesem Zusammenhang müssen neue Fähigkeiten identifiziert und ausgebildet werden, die ein effizientes kommunikatives und strategisches Handeln an der Schnittstelle zwischen Unternehmen und Kunden sicherstellen [PI09].

4.7 Strategie 7: Innovative Formen der Arbeitsorganisation

Die Modernisierung der Arbeitsorganisation aufgrund grundlegender Veränderungen der Arbeitswelt erscheint immer wieder als Thema bei Arbeitnehmern, Management und politischen Entscheidungsträgern [Tot04] (vgl. Grünbuch 1997: 128, zit. n. [Tot04]). Ausgangspunkt dieser Veränderungen ist der zunehmende organisationale als auch individuelle Flexibilisierungsdruck sowie die sich ständig ändern-

Abb. 10 Gestaltungsmerkmale der Strategie „Management der Ungewissheit"

den Anforderungen an das arbeitende Individuum. Betrachtet man die Arbeitswelt unter den Bedingungen globalisierter, dynamischer Ökonomien und ständiger Fluktuationen bei der Nachfrage von Waren und Dienstleistungen, dann ist sie geprägt von zunehmendem Flexibilisierungsdruck hinsichtlich austauschbarer Kompetenzen und anpassungsfähiger Arbeitsformen. Damit Unternehmen und Menschen in diesem neuen Umfeld motiviert, handlungs- und vor allem innovationsfähig bleiben, bedarf es umfassender Modifikationen der Arbeitsorganisation, die nicht mehr am Paradigma der Kostenreduktion und schlanker Prozessgestaltung orientiert, sondern auf die Nutzung und Förderung des Humankapitals ausgerichtet sind [fH07]. Vor diesem Hintergrund müssen Unternehmen innovative Formen der Arbeitsgestaltung einführen, die Freiräume zum Lernen eröffnen (z. B. Teamlernen) und Möglichkeiten zulassen, Fähigkeiten zu entfalten (z. B. Teamarbeit). Auch flache Hierarchien, bei denen im Gegensatz zur steilen Hierarchie verstärkt auf Eigeninitiative und -verantwortung gesetzt wird, gewinnen zunehmend an Bedeutung.

4.8 Strategie 8: Management der Ungewissheit

In Abhängigkeit von spezifischen organisationalen Rahmenbedingungen erfordern die ansteigende Turbulenz, Dynamik und Komplexität der Unternehmensumwelt die Ausbildung neuer Kompetenzen auf individueller und organisationaler Ebene. Für die Unternehmensführung und Mitarbeiter gleichermaßen werden Entwicklungen und Veränderungen der persönlichen Arbeitssituation immer schwerer kalkulier-

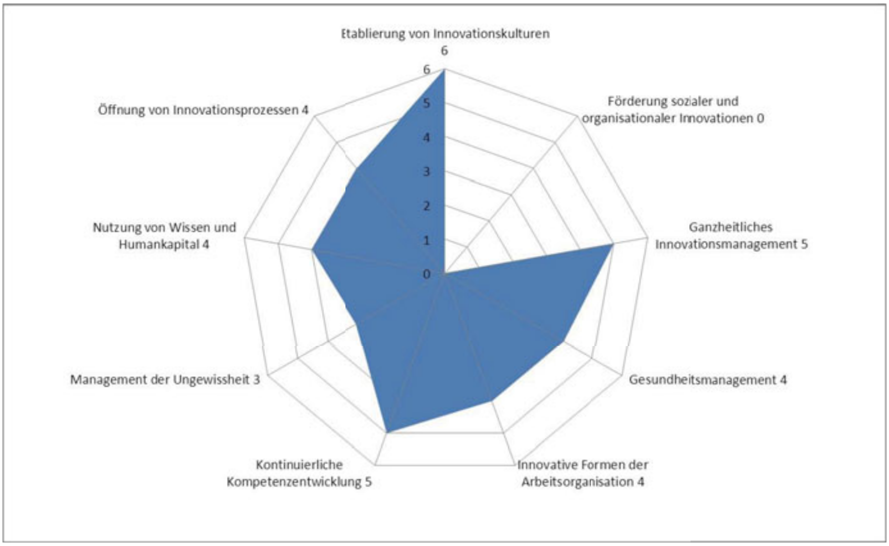

Abb. 11 Qualitative Verteilung von Gestaltungsmerkmalen nach Strategien

und planbar. Diese Situation der permanenten Ungewissheit und Unvorhersehbarkeit trifft Unternehmen besonders da, wo sie kompetitiv und innovationsfähig sein müssen [Gro02]. Vor allem Innovationsvorhaben und -prozesse erfordern eine hohe Risikobereitschaft und großes Vertrauen in das Unplanbare – Innovativ ist nämlich meistens nur das, was eben nicht vorhersehbar ist [Gro99]. Der Umgang mit Ungewissheit wird damit zu einer zentralen Fähigkeit, um unter flexiblen und dynamischen Bedingungen innovationsfähig bleiben zu können. Für den erfolgreichen Umgang mit Ungewissheit sowie für die Umsetzung von Innovationen ist dieständige Aktualisierung der eigenen Kenntnisse notwendig. Die untersuchten Unternehmen begegnen der Ungewissheit vor allem mit einer zielgerichteten Marktforschung und dem Vertrauen in die Selbstorganisation jedes Mitarbeiters. Auch das Erschließen z.T. branchenfremder Märkte, d. h. das Ablassen von der Fokussierung auf ein Marktsegment, hat sich als Mittel zur Bewältigung des Unplanbaren bewährt.

Insgesamt konnten anhand der qualitativen Auswertung der Workshops 35 innovationsförderliche Gestaltungsmerkmale identifiziert und mit Strategien verknüpft werden. Den Strategien „Etablierung von Innovationskulturen“ (6), „Kontinuierliche Kompetenzentwicklung“ (5) sowie „Ganzheitliches Innovationsmanagement“ (5) konnten verhältnismäßig viele Gestaltungsmerkmale zugeordnet werden. Demgegenüber weist die Strategie „Förderung sozialer und organisationaler Strategien“ (0) keine relevanten Merkmale auf (vgl. Abb. 11).

5 Problemfelder und ungenutzte Innovationspotentiale

Obwohl die Strategie „Förderung sozialer und organisationaler Innovationen" im Kontext des IMO-Projektes als adäquate Unternehmensstrategie zur Steigerung der Innovationsfähigkeit identifiziert wurde, wird sie bei der Ergebnisdarstellung nicht berücksichtigt. Daraus ist zu schließen, dass Unternehmen die im Zusammenhang mit sozialen und organisationalen Innovationen stehenden Innovationspotentiale (noch) nicht ausreichend wahrnehmen.

Soziale und organisationale Innovationen werden demnach in der Unternehmenspraxis wenig und zumeist nur in Bezug auf technische Innovationen zur Kenntnis genommen und analysiert. Mit dem Wandel zur Wissens- und Dienstleistungsgesellschaft sowie der wachsenden wirtschaftlichen und beschäftigungspolitischen Bedeutung zeichnet sich aber ein Paradigmenwechsel im Innovationsverständnis und -system ab [Bul06]. In der Folge dieses Paradigmenwechsels verändert sich das Verständnis von technologischen, sozialen und organisatorischen Innovationen. Zielte der Begriff „Innovation" bisher primär auf die natur- und ingenieurwissenschaftlich geprägte Hervorbringung neuer Produkte und Verfahren ab, werden in Zukunft soziale und organisationale Innovationen stärker in den Fokus rücken [HKS08]. Unter sozialen Innovationen werden von bestimmten Akteuren bzw. Akteurskonstellationen ausgehende intentionale, zielgerichtete Neukonfigurationen sozialer Praktiken verstanden, mit dem Ziel, Probleme oder Bedürfnisse besser zu lösen bzw. zu befriedigen, als dies auf der Grundlage etablierter Praktiken möglich ist [HJ10]. Organisationale Innovationen sind hingegen auf erfolgreiche strukturelle, prozessuale oder humanorientiere Neuerungen der Modifikationen innerhalb von Organisationen bezogen. Es zeigt sich jedoch, dass diese „weichen" Arten von Innovationen sowohl in der Praxis als auch in der Forschung immer noch zugunsten einer einseitigen Betrachtung von technikorientierten Produktinnovationen vernachlässigt werden. Dies ist insofern bedenklich, als dass aktuelle Studien [HS10] zeigen, dass insbesondere organisationale Innovationen enormen Einfluss auf Produktivität, Innovationsfähigkeit sowie die Gelingenswahrscheinlichkeit von technischen Innovationen haben. Für eine nachhaltige und effiziente Implementierung von sozialen und organisationalen Innovationen sind zukünftig vor allem folgende Barrieren zu überwinden:

- Geringes Bewusstsein für die innovative Praxis und ihren Nutzen bei Managern/Entscheidungsträgern, Sozialpartnern und Unternehmensberatern
- Mangelnder Zugang zu evidenz-basierten Ansätzen, die interorganisationale Lern- und Innovationsprozesse unterstützen
- Widerstände auf der mittleren Führungsebene, die sowohl die Ausführung als auch die Verantwortung organisationaler Veränderungen tragen muss.

Fagerberg beschreibt die Variabilität des Innovationsbegriffes als eines seiner zentralen Kennzeichen: „One of the striking facts about innovation is its variability over time and space. It seems, as Schumpeter... pointed out, to 'cluster' not only in certain sectors but also in certain areas and time periods" [FMN05]. Im Hinblick auf den Erhalt bzw. die Steigerung der Innovationsfähigkeit bei KMU ist es notwendig, den beschriebenen Paradigmenwechsel bei der Gestaltung organisationaler Rahmenbedingungen und Arbeitsabläufen stärker zu berücksichtigen.

6 Zusammenfassung und Ausblick

Innovationen zu generieren ist vorrangiges Ziel für Unternehmen, nicht nur im industriellen Wettbewerb. Die tendenziell steigenden Ausgaben für die Generierung neuer Produkte belegen die großen Hoffnungen, die mit Innovationen verbunden sind. Die erfolgreiche Umsetzung von Ideen in den alltäglichen Gebrauch einer Organisation ist somit eine der zentralen Management-Aufgaben der heutigen Zeit. Entscheidungsträger sind mehr denn je gefordert, innovationsförderliche Rahmenbedingungen zu schaffen, die dazu führen, dass insbesondere das vorhandene Wissens- und Humanpotential der Mitarbeiter aller Hierarchieebenen stärker identifiziert und genutzt werden kann. Der Artikel beschreibt neun Strategien, die in dieser Hinsicht für eine gezielte Ausgestaltung eines Unternehmens genutzt werden können. Darüber hinaus wurden im Rahmen von Innovationsworkshops mit innovativen KMU praktische Gestaltungsmerkmale zu jeder Strategie eruiert. Die hier skizzierten Ergebnisse sind als „Gestaltungskatalog“ zu verstehen, der Entscheidungsträgern bestimmte Handlungsoptionen aufzeigt, um die Innovationfähigkeit seines Unternehmens zu steigern. In diesem Zusammenhang ist zu beachten, dass die Strategien und Gestaltungsmerkmale in wechselseitiger Beziehung zueinander stehen und sich gegenseitig verstärken oder beeinträchtigen können. Aus diesem Grund ist die strategische Ausrichtung zur Stärkung der Innovationsfähigkeit nicht in einem generalisierbaren Vorgehensmodell zu fassen. Vielmehr müssen die jeweiligen spezifischen Gegebenheiten (Unternehmensgröße, Unternehmensumwelt, Mitarbeiter, Struktur, Führungskultur, etc.) präzise analysiert werden, um sich anschließend passgenauer Strategien und Gestaltungsmerkmalen bedienen zu können.

Die Innovationsfähigkeit eines Unternehmens umfasst die Vielfalt der Kompetenzen, die notwendig sind, um Neues zu entwickeln – von der Idee bis zur Realisierung. Verbesserungen in Bildung, Ausbildung sowie die Kompetenzentwicklung in der Arbeit sind entscheidende Grundlagen zur Stärkung der Innovationsfähigkeit. Denn: Innovationen werden von Menschen gemacht. Dies bestätigen auch die identifizierten Gestaltungsmerkmale, die sich zum Großteil direkt oder indirekt auf die Fähigkeiten und Kompetenzen der im Unternehmen handelnden Menschen beziehen lassen.

Ungenutzte Innovationspotentiale ergeben sich v.a. im Zusammenhang mit sozialen und organisationalen Innovationen, die trotz ihrer wachsenden Bedeutung häufig nur als Voraussetzungen, Begleitumstände oder Folgen technischer Innovationen zur Kenntnis genommen werden. Dabei ergeben sich insbesondere durch die steigende wirtschaftliche und beschäftigungspolitische Bedeutung des Dienstleistungssektors vielfältige Optionen. Die vordringliche zukünftige Forschungsaufgabe ist zum einen die Analyse der Wechselwirkungen und zum anderen der Synergiepotentiale zwischen den identifizierten Gestaltungsmerkmalen. Darüber hinaus müssen die Gestaltungsmerkmale durch weitere quantitative Studien verifiziert werden.

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Design and Application of a New Workshop Concept on the Development of an Innovative Transport Unit

A New Way of Knowledge Sharing

Sebastian Jursch, Eckart Hauck, Richard Ramakers, Sabina Jeschke, Klaus Henning

Abstract For a product-oriented project, the product development in particular the design and decision phase is of a high relevance. In this phase and based on the identified requirements, ideas and solutions are summarized, evaluated and filtered. In the interdisciplinary research project "TelliBox" (within the 7th work program of the European Union) an innovative container for the intermodal transport has been developed. Within the consortium the diversity of ideas and images to realize such a container was huge and common approaches, particularly for the filtering and combination of the best possible solutions, seemed not very promising, since they were not able to integrate all participants into the process. Thus, the procedure of solution-finding and filtering turned out to be rather inefficient and uneconomical. Therefore a new workshop concept was developed that allowed to summarize, evaluate and filter solution proposals. The concept was used for a heterogeneous project consortium, with divergent desires and requirements, during the solution development. The workshop's aim was to consolidate the individual images and ideas of the 25 participants (researchers, developers, operators, freight forwarders, etc.) and to define of about three to five plausible solutions. These had to fulfill all technical requirements and needed to be accepted by all stakeholders before they were worked out in detail and finally decided on. The workshop concept was split in five communication levels ("Dialog", "Inner Dialog", "Exchange within Groups", "Exchange between Groups" and "Exchange within the Consortium") where different processes were located. These processes involved several methods like speed dating, morphological analysis, poster session etc. accompanied by methodical working phases like individual work, group work or even work in the whole consortium. This new approach to the creation of ideas and the sharing of knowledge showed that solution finding processes can be shortened and that the integration of all relevant participants lead to an innovative and feasible solution. Thus, the product development was accepted by all parties and was successfully accomplished without any compromises

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concerning the requirements. The fact that all project partners were able to present their own ideas and discuss them without any prejudices promoted the approval and acceptance of the decisions made. Through their involvement the partners were also much more interested in the next steps of the project.

Key words: Knowledge Sharing, Workshop, Product Development, Transport

1 Introduction

1.1 Initial Situation of Freight Transport

In the last decades intermodal freight transport was driven by the changing requirements of global supply chains. The improved integration and compatibility between modes provided the necessary scope for a sustainable transport system and the promotion of intermodality offered the opportunity to improve rail, inland waterways and short sea shipping. Presently, these options are seldom used, because they do not allow door-to-door delivery. In future the operation grade of carriers will increase significantly and the European Commission prognoses a suboptimal load of rail and waterways compared to the undue quantity of road transports [Com06].

The road transport system is almost overloaded and currently does not offer enough potential for technological enhancement to face the future increase in traffic. Hence, balancing the modes of transport i.e. intermodal transport is crucial for European transport policies. Today's transport system has to face various challenges in terms of safety, reducing traffic congestion and the improvement of loading processes and interoperability of available transport modes. Furthermore the creation of a sustainable transportation system for Europe depends on the cooperation of operators along the transport chains. For a competitive intermodality the quality and flexibility of interfaces between modes and national transport chains needs to be increased. Additionally, transport costs may be reduced by pursuing the trend towards high-volume loading units. Concerning the dimensions of the loading units, some transport modes may not meet the requirements of every cargo. The lack of standardization of intermodal loading units inhibits the connectivity of modes and generates costs e.g. through the requirement of special transshipment technologies.

Especially developed transport solutions, like the high-cube containers or jumbo semitrailers and loading facilities, for example curtain-side swap-bodies or boxes with liftable tops, were introduced to the market. However, those single solutions often can only be used for special applications and require special operational technologies so that extra costs arise.

The success of intermodal transport solutions compared to road transport significantly depends on the cost efficiency of loading processes, the improvement of interoperability and the exploitation of a maximized cargo area.

European policies and socio-economic changes had a strong impact on the demand on transport. Despite the positive development of the modal split, intermodal

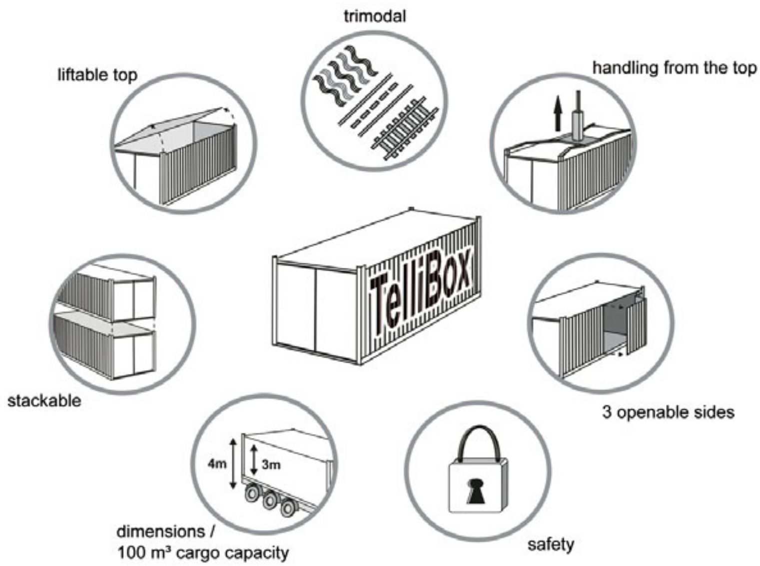

Fig. 1 Necessary requirements for the new transport unit

transport is hampered by technical constraints particularly when it comes to the standardization of the loading units and transshipment technologies. Therefore intermodal transport lacks all-purpose products.

Currently, many different loading units are used in European freight transport. ISO-Containers, swap-bodies and semitrailers have been adapted for certain purposes and markets. A general tendency to enhance loading units affects the maximization of the cargo area and the facilitation of loading and transshipment processes. These loading units differ in their dimension and stability as well as their usability regarding handling, transport and loading processes.

The project "TelliBox – Intelligent MegaSwapBoxes for advanced intermodal freight transport" was launched due to the increasing demands from politics and society to counteract the trend towards increasing freight transport on roads. It focused on the development of an all-purpose loading unit, applicable in intermodal transport of road, rail, inland and short sea shipping. The aim was to optimize the concept and design of swap-bodies by combining the advantages of containers and semitrailers for a sustainable intermodal freight transport. This new transport unit will also represent an optimal solution regarding technical feasibility. The objectives of this project were based on the experience of logistic companies, who have been operating in intermodal freight transport for years.

Such a transport unit needed to face several requirements regarding its design and functionality (see Fig. 1). One objective was the introduction of the transport unit to the intermodal market and the long-term positioning of new units, which have to be able to compete with long-established loading units and unimodal solutions.

1.2 Initial Situation of the Product Development in Transport

Companies, who want to be successful on the market, face some major challenges. Not only do they have to ensure that their product meets the consumer's desire, but they also have to consider the quality and the costs of the product development. For the economical design of a product the development has to be achieved with minimal expense and in the shortest time possible. At the same time the product is expected to be of high quality. It for example has to be made of high-quality industrial components to reduce expensive repairs and expenditure of time. Furthermore, a high product performance and product capacity have to be ensured in order to guarantee safety and reliability. These are the basic requirements, which can limit companies in their search of ideas for new products. In order to develop products in the most effective way, an adequate approach beginning early in the development is therefore needed to obtain the best solution and most suitable strategy.

The application of innovative solution-finding-methods (to generate new innovative products) is essential for the survival of a company. But this is no longer an exclusive task for the research and development department. It has become a trans-sectoral process in which the demands of intern divisions like the marketing department, the manufacturing department, the financial department, the suppliers and the assembly as well as the client's or customer's wishes has to be considered. The appropriate implementation of these demands and wishes into the product design allows a faster progress in development, product launching and cost reduction.

Nowadays problems become more and more complex. Companies have to rely on the knowledge and support of their staff and stakeholders. Now the question is what is the most attractive and effective method to share knowledge and create solutions?

A variety of different engineering and idea-finding approaches can be found in literature and practice. Methods like the theory of inventive problem solving (TIPS/TRIZ) [Orl05] or the developing-method due to Pahl/Beitz [PB07] – to name just a few – have become very popular, as well as the stage-gate-method [Coo02]. Further, one has to mention the technical attractiveness [Stu03] method, which combines the design and decision phase, the value benefit analysis [Zan70] and the sensitivity analysis [Ves07] to identify the most attractive solutions.

All these approaches show considerable disadvantages, such as extreme expenses considering time and effort and therefore costs, accompanied by little flexibility, high complexity or lack of motivation caused by delayed success or failure.

For example, the major disadvantage of the TRIZ-method is the extensive training in advance due to the complexity of the method. So it is a very time-consuming and costly process. Furthermore, an expert of the TRIZ method is needed to moderate the solution-finding-process by whom the participants may be unconsciously manipulated towards a certain direction. Whereas, the ETA-method is characterized by a high inaccuracy and error rate due to a vague estimation of probabilities. The method invented by Pahl and Beitz tends to increase the overall complexity as soon as the scope for functional sharing is reduced. This often leads to manufacturing problems, such as a higher parts count. Cooper's stage-gate-method fails because of the tension between the organization and development stage. His original method did not deal with the solution-finding-process and the technical attractiveness with its sensitivity analysis and value benefit analysis is too abstract for the partners from industry. The value benefit analysis by Zangenmeister however is problematic when it comes to the reduction of solution alternatives, with more than one decision-maker. This leads to difficulties in the criteria selection and raises costs due to delays. It proved to be impossible to achieve the desired result just with one of those well-known methods.

2 Methodology for the Development of an Innovative Transport Unit

The aim is to find an optimal and technical feasible solution followed by the construction of a prototype. An interdisciplinary European consortium consisting of operators, logistic enterprises, manufacturers and research institutes are involved in the development of a transport unit as a compromise between existing solutions and new innovative approaches. The European research project, TelliBox aims to generate an applicable and custom-oriented intermodal transport solution by encouraging dialogue between industrial and scientific partners.

The developed scientific methodology (see Fig. 2) is subdivided into six essential phases. At the beginning of the development of a new transport unit an extensive analysis phase was implemented. This included the analysis and prioritization of all technical, operational and constructive requirements of the new transport unit and the development of a solution space. This phase was important to guarantee the design of a system that was most suitable for intermodal transport. The solution space considered new approaches and component technologies which are on the market to create variants. It is essential that all partners of the consortium are involved.

Within the second phase, the new workshop design was used to create possible solutions. A combination of various methods like speed dating, morphological analysis etc. was used. As a result of the design phase approximately three concepts, which appeared to be the most suitable (technically and operationally) for the transport system, were formed. The third phase comprised the elaboration of the chosen variants of the transport unit and the adapted chassis. In addition, simulation methods like the 'finite element method' were used for further analysis of the design.

Before a prototype is built, the solutions were evaluated in the next phase. Within this evaluation phase, the concept of the best design was chosen and a prototype based on this design is setup. For this purpose different calculations of economic efficiency were carried out and the usability of all concepts was evaluated.

After the identification of the most economically, operationally and technically suitable design the prototype of the transport unit is produced within the fifth phase. The last phase comprises the testing of the prototype for all transportation modes (road, rail, short sea and inland shipping), and the handling processes in terminals.

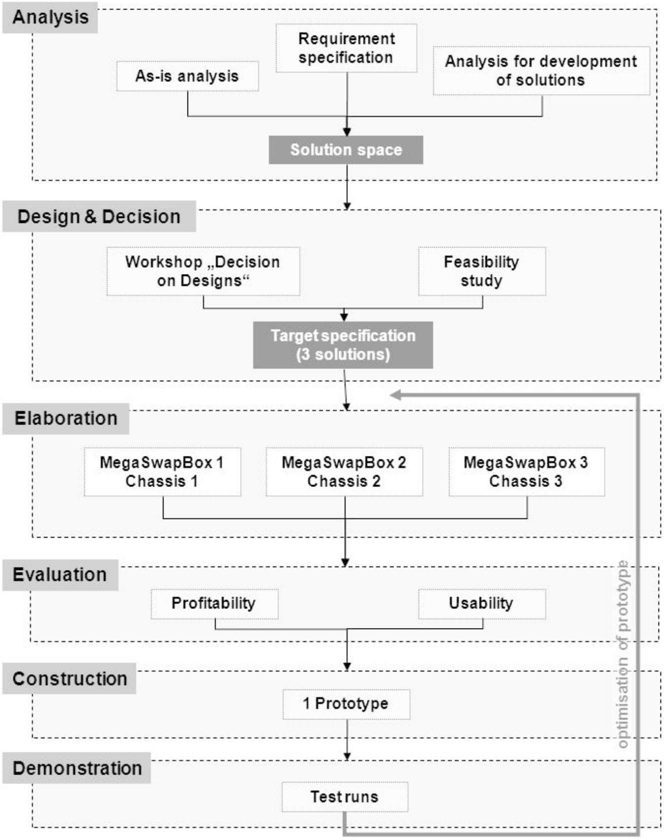

Fig. 2 Methodology for the development of an innovative transport unit

In addition, tests concerning the loading and unloading of freight are carried out. The result of the test phase delivers an evaluation of the quality of the prototype that considers both technical and operational aspects. Recommendations are then developed to optimize the system.

The results of the testing phase are used to improve the prototype of the transport unit. Therefore, an optimization loop is integrated within the methodology. The recommendations are used as a foundation to improve the design within the third phase. However, the optimization of the prototype should not involve a complete redesign of the transport unit, rather the modification of individual components. After reengineering, the prototype is tested and evaluated like beforehand.

Because of the above mentioned problems of finding and generating new solutions for the development of a new transport unit, the paper will focus on the design workshops, which belong to the most important phase, the design phase (Fig. 3).

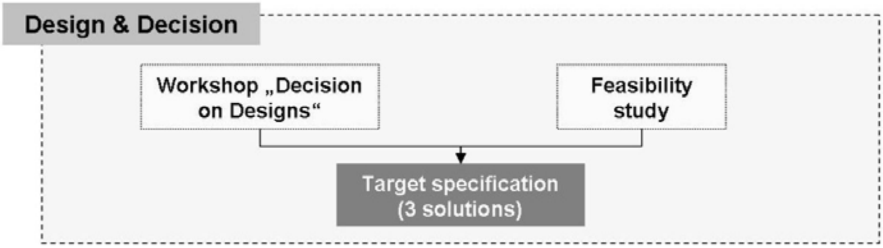

Fig. 3 Design & Decision phase

3 Design of the Workshop Concept

A new workshop concept, also called “Decision on Designs Workshop”, was developed to be used in the design stage for the solution development (Fig. 4). The workshop begins with drafts of possible solutions and ending with a clear definition of plausible solution hypotheses, which have to be accepted by all stakeholders. At the same time, these solutions have to meet all technical requirements.

Afterwards, the solutions are elaborated in detail and thereafter evaluated regarding criteria like profitability, usability etc. before an optimal solution can be chosen.

It is intentioned to take individual ideas and images to form one accepted solution. This involves a lot of communication and exchange between all participants, which is why the workshop concept is divided into different levels of communication [LeM01]. These levels are the “Inner Dialog”, the “Dialog”, the “Exchange within Groups”, the “Exchange between Groups” and the “Exchange within the Consortium”. In these five levels of communication different process methods are used, where feedback is allowed at all times. These methods and processes follow a defined sequence and go through different levels. The first level describes the “Inner Dialog” where the individual is concerned with its own ideas and solutions. Within this level the “Own Drafts” method is used, where each person has to develop its own drafts to solve the formulated problem. “Improvement & Documentation” is reserved for the improvement of e.g., the own draft and the documentation of the feedback and the draft itself. This process can also be applied in other communication levels.

The second level “Dialog” deals with the dialog between two persons. This leads to an intensive exchange and is realized by the use of the speed dating method. This method was employed here, since the key factors cost, time and effort played a major role in the development of the workshop concept. The original speed dating strategy for busy professionals to optimize the time they spend while dating, is modified for the industry to offer a more efficient way to share knowledge and find solutions. The aim is to get acquainted with all of the design concepts and to discuss them in a structured way.

The third level “Exchange within Groups” incorporates the communication, exchange and working within a group of a defined size. One method used is the mor-

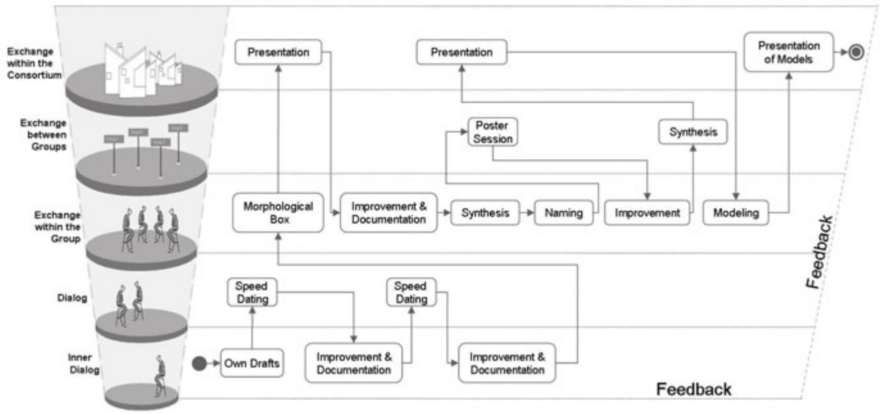

Fig. 4 Design of the workshop concept

phological box. It presents solution possibilities and is therefore a useful instrument for an overview and selection. The morphological analysis was designed for multi-dimensional, non-quantifiable problems, where causal modelling and simulation do not function properly or not at all. Fritz Zwicky developed this approach to a, as it seems, non-reducible complexity [ZW67, Zwi69]. In this case the morphological box offers the possibility to indicate the totality of the conceivable solutions for a given problem. Therefore the variable creation elements (= parameter) of potential solutions have to be set. They are arranged as a preliminary column in a table. Behind every parameter all conceivable concrete execution possibilities (= characteristic) are listed. Single solution alternatives originate from the fact that one chooses a characteristic from every parameter line and connects them with each other. The genetic principle of the solution finding is the systematic combination. The process step "Synthesis" means the combination and synthesis of solution approaches as well as ideas. The process "Naming" should strengthen the connection to the developed solution by giving the product a name. In the "Modeling" process a model is built. This shows possible chances and risks of every concept as well as the working principle of the design itself. It also provides a better understanding of form, functions, dimensions etc. "Detailing" means the detailing and refinement of the worked out solutions. This process might have to be accomplished after the workshop in a defined time frame. Because of the complexity of the problem and especially of the solution several investigations are required. These investigations can be too time-consuming to be handled within the workshop.

The fourth level "Exchange between Groups" is primarily concerned with the communication and the exchange between the groups. Here, for example the process "Poster Session" is located [Bri96]. The individuals can question the representative on the presented solution and thus are able to solve there own issues.

The last level "Exchange in Consortium" means working, communication and exchange within the whole consortium. The process "Presentation" guarantees the same level of information for all individuals through the presentation of the results etc. in front of the consortium.

4 Application of the Workshop Concept

In this case, 25 participants, using a newly designed workshop concept, worked out a solution for a new intermodal transport unit that fulfils all technical requirements and is accepted by all stakeholders At the beginning, every workshop-member, irrelevant whether being a technician, consultant, scientist, businessman etc., sketched his/her possible solution and made a draft of an own transport unit. Here, they could use the already elaborated ideas and solutions of the solution space or they generated new ones by themselves or simply combined different possibilities. These drafts were used right at the beginning of the workshop. Afterwards the speed dating method was applied. The aim was to get acquainted with all of the design concepts as well as to discuss them in a structured way. To guarantee this structured approach, every participant received a "date plan", a list of evaluation criteria and a form for remarks, improvements and feedback. The "date plan" ensured that all participants had the chance to "date" all members of the workshop. A common approach and understanding was ensured through the evaluation criteria and its description. The form provided a standardized way of reporting.

Each participant was alternating between:

A: Presentation of the design to the partner and the reception feedback.
B: Listening to the presentation of the partner's design and then giving feedback.

The speed dating was split into two parts. Each part was followed by an improvement and documentation loop where the participant could precise, adjust and specify his design.

The speed dating part itself was followed by group work. The hosts built small groups of three or four persons based on the analogy of designs and the expertise of each participant. Aim of this work group session was to put all idea and solution proposals in a morphological box. The filled morphological boxes of every group were presented and discussed within a plenary session in order to obtain the same level of information. After a new improvement and documentation loop the solutions were synthesized in groups according to a provided requirement specification. The group also had to define a way how these requirements can be fulfilled or why they were doomed to fail. Additionally, every group had to name their solution to promote the identification with their product and own work. To exchange information each group prepared a poster of its design and presented it within the poster session. The received feedback and suggestions were implemented in the following improvement loop that gave the group the opportunity to improve their design.

During the last part of the workshop the group had to undertake two tasks simultaneously. One was to build a model of the concept on a scale of 1 : 32 made of balsa

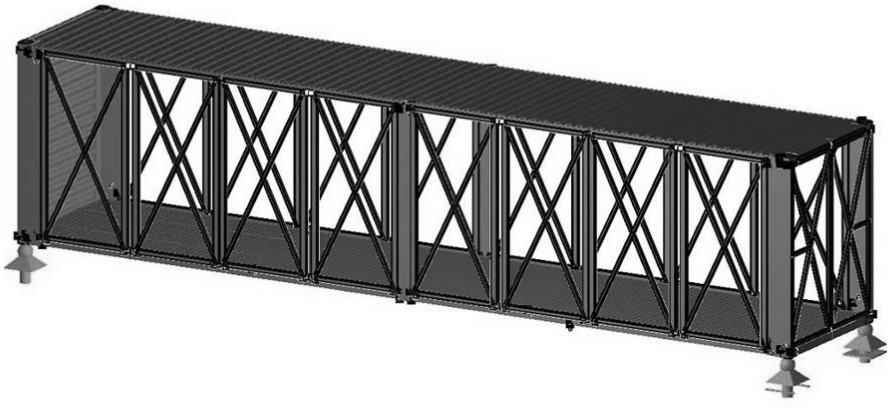

Fig. 5 Developed solution of the new transport unit

wood where they had to include the essential features of the design and on the other was to document the concept and the solution in detail.

Next the detailing of the concepts and the filtering by methods e.g., profitability analysis and usability studies, to one final design took place (Fig. 5).

5 Conclusion

This novel approach for the creation of new solutions and knowledge sharing proves that solution finding processes can be abbreviated while simultaneously all relevant actors are integrated. As our example showed all drafts were introduced at the beginning by the speed dating method within the short timeframe of only three hours – which equals an accumulated speech time of fifty hours. Such an efficient and intensive information exchange process cannot be achieved by other approaches since information exchange processes usually take far too long or do not obtain comparable results due to the absence of suitable conversation guidance.

Thus this innovative approach allows a successful product development with the acceptance of all parties, since it encourages the participation of all project partners in the whole solution-development-process and gives them the possibility to contribute their own ideas and to discuss them without prejudice. In this way the mutual acceptance towards the final decision on a design is increased. Furthermore, the new method promotes the interest in the next steps of the project, since all project partners are involved.

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Trust Is Good, Control Is Better
An Open Innovation-Controlling for SME

Jessica Koch, Eckart Hauck, Ingrid Isenhardt

Abstract Until now the practical work concerning Open Innovation was focused on the conceptual and use-oriented field. Both the methods and their potentials are depicted but there is no research on the cost-effectiveness of Open Innovation and the applicability of its methods – especially in Small and Medium Enterprises (SME). Currently SME have no instrument helping them to decide whether they should adopt Open Innovation. Hence it is necessary to create such an instrument to give the SME support to decide if "the formal discipline and practice of leveraging the discoveries of others as input for the innovation process through formal and informal relationships" [RP08] is worthwhile. In this paper the research project "Invoice – Efficiency of Open Innovation for Small and Medium-sized Enterprises" is presented. Within this project the Institute for Management Cybernetics e.V. (IfU) and the Technology and Innovation Management Group (TIM) at RWTH Aachen University develop an instrument to control Open Innovation-methods in SME.

Key words: Open Innovation, SME, Controlling, NOWS, Critical Success Factors

1 Open Innovation

The successful generation of innovation is a company's constant assignment, especially for the numerous technology-oriented SME in Germany [Sch05]. The reason is the rapid technical change and with this the decreasing development times of products. Enterprises have to keep up with these changes otherwise they will not be able to be competitive anymore. Due to that, the pressure to innovate is rising. Therefore the ability to develop innovation is the key for lasting company success [Sch05]. Furthermore, many enterprises are not able to bring their new product de-

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velopments onto the market [Fra07]. As a significant development within innovation management in the last couple of years is the amplified comprehension of external contributors such as customers, suppliers, researchers and universities can be observed [Che03]. They are involved in the entrepreneurial innovation process. Due to the businesses' objective of achieving a successful generation of innovation the development process is opened for external players during all phases of the product development process. Therefore the involvement of external players begins with the idea generation phase and ends with the product and prototype test phase [Che03]. The Danish enterprise Lego for example is adopting Open Innovation. They started the integration of the external knowledge of their stakeholders into their process of innovation in the late 1990s when Lego launched the Mindstorms (programmable robots). Some consumers were able to crack the source code and published it on the internet. Lego decided to seize this chance and use the consumers' knowledge to create the second generation of Mindstorm robots [Wil07]. Users, who extend the range of applications of existing products, develop them further and create their own prototypes, are known as Lead-Users [TW08].

Open Innovation is also used successfully in some SME. Many enterprises use this form of innovating products unconsciously: they take part in public-aided research projects for example. Consequently they integrate researchers into their innovation management. Beside the short resources the disclosure of a part of their knowledge means also a problem for SME. To focus on the main issue it could be said that SME neither know how to use the Open Innovation-strategy nor how much of their knowledge they have to externalize without risking too much of it. A method which proves the effectiveness and efficiency of Open Innovation-techniques still does not exist.

2 The Research Project Invoice

The instrument to control Open Innovation-methods which has to be developed in the research project "Invoice" will be based on the use-oriented cost-effectiveness evaluation by Weydandt [Wey00]. By using this tool it will be possible to take measurements both ex ante (to aid the decision-making process concerning the implementation of Open Innovation in SME) and during the process of innovation. Also it allows analyzing "hard" and "soft" factors of the Open Innovation-measures. The conventional measurement-tools of the cost-effectiveness (for example the ROI) will be replenished by implicating the benefit of Open Innovation in SME. To achieve the aim of designing the new controlling concept especially for SME and helping them to integrate and use the Open Innovation-strategy, it is necessary to analyze the special characteristics of small and medium sized enterprises.

According to Gassmann and Widenmayer [GW10] the special barriers respective the integration of Open Innovation in SME are the Not-Invented-Here-Syndrome (NIH-Syndrome) as well as the Not-Sold-Here-Syndrome (NSH-Syndrome). Both have to be removed. The NIH-Syndrome describes the non-observance of external knowledge, which is quite known (cf. Katz/Allen 1982). The "hoarding" of internal

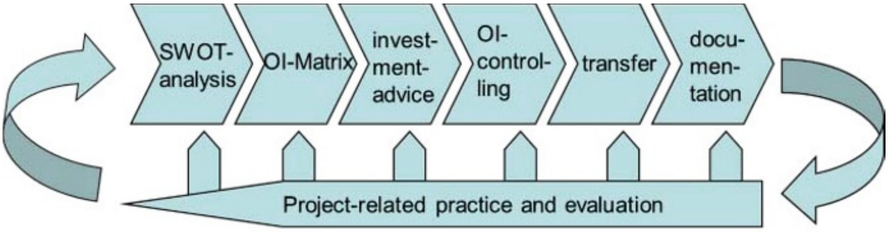

Fig. 1 The research project's procedure

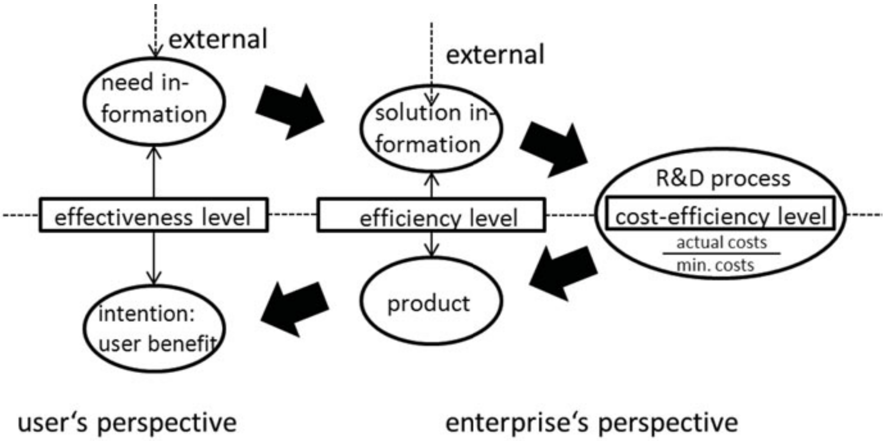

Fig. 2 The 3-Level-Model of the innovation controlling based on Hilgers and Piller, 2009 [HP09]

knowledge inside the enterprise in order to avoid the intellectual property to leave the enterprise and its commercialization is known as the NSH-Syndrome [GW10]. Hence the characteristics of SME will be analyzed and, after this, critical success factors concerning the SME's management of innovation will be identified. This would be necessary to come up with the requirements which have to be fulfilled by an instrument to control Open Innovation-methods. The instrument, to secure both the measurement of the Open Innovation's effectiveness as well as the measurement of its efficiency, will be based on a Balanced Scorecard (BSC) approach. A special challenge of this integrated measurement is the development of key figures which could map all the perspectives inside the innovation process as well as the integration of external knowledge into the entrepreneurial value chain (Fig. 1).

At the end of the research project "Invoice" a control loop based instrument, which controls the effectiveness and efficiency of Open Innovation-projects in SME, will have been developed. Figure 2 shows how the developed performance measurement system has to map the three aspects effectiveness, efficiency and cost-efficiency of Open Innovation processes [HP09].

3 The Open Innovation-Controlling

The controlling instrument, which will be developed in the research project Invoice, has to support three levels of the Open Innovation-process:

1. It has to support the decision process, if the SME should use Open Innovation or not.
2. It has to manage the whole Open Innovation-process.
3. It has to be able to evaluate the process at the end to find out, if Open Innovation was the right way.

This article focuses on supporting the decision process, if the SME should use Open Innovation or not. For this a value-oriented cost-effectiveness estimation is needed. The costs and benefits of using Open Innovation have to be evaluated by the SME before they decide if they should use it in the context of a current problem. This evaluation provides a basis for the decision.

The developed method has to combine the classical analysis of investment in monetary terms with relevant non-monetary variables or the so-called soft factors in the profitability analysis. This approach needs to be considered in comparison to the classical economic efficiency approaches: these conventional approaches limit themselves basically to the quantifiable objectives in terms of monetary data, e.g. costs and revenues (so called "harder" factors). In contrast, the new approach has to consider non-monetary objectives such as time, quality, flexibility, employee perspectives or enterprise environment to be evaluated in terms of money.

To create such a supporting instrument the Value Oriented Cost-Effectiveness Estimation (NOWS) could be used as a basis [UHS04]. It consists of seven phases which form the basis for all participation-oriented processes as well as the learning processes [Ung98] of all participants and also the organization. In the phase "Constitution of the Interdisciplinary Investment Team", a representative team is created from executives and employees who are affected by the measures and strategies; this team conducts the whole evaluation, implementation and reflection process. During the phase "Current-Situation-Analysis", the existing skills and competencies in the enterprise are identified; in the "Target-Situation-Analysis" phase, the necessary competencies are derived from the strategic objectives, and are identified and classified according to the necessity of reaching them. Step 4 "Compilation of Measures" defines individual strategies, which are then tested for their economic efficiency in the "Investment calculation and evaluation" phase. This is the core phase of the NOWS. Within this phase the costs and benefits of the investment get defined and assigned, if they are direct, indirect or difficult ascertain to their probability of occurrence is high, medium or low. The evaluation is concluded by the decision to implement one or several strategies. The benefits as well as the costs get summarized in a 3×3-matrix containing the occurrence probability and the ascertainability. Afterwards costs and benefits get monetized and accumulated from direct ascertainability and high probability of occurrence to difficult ascertainability and low probability of occurrence. Afterwards the accumulated costs and benefits get displayed in a NOWS chart. The intersection point of the cost graph and the

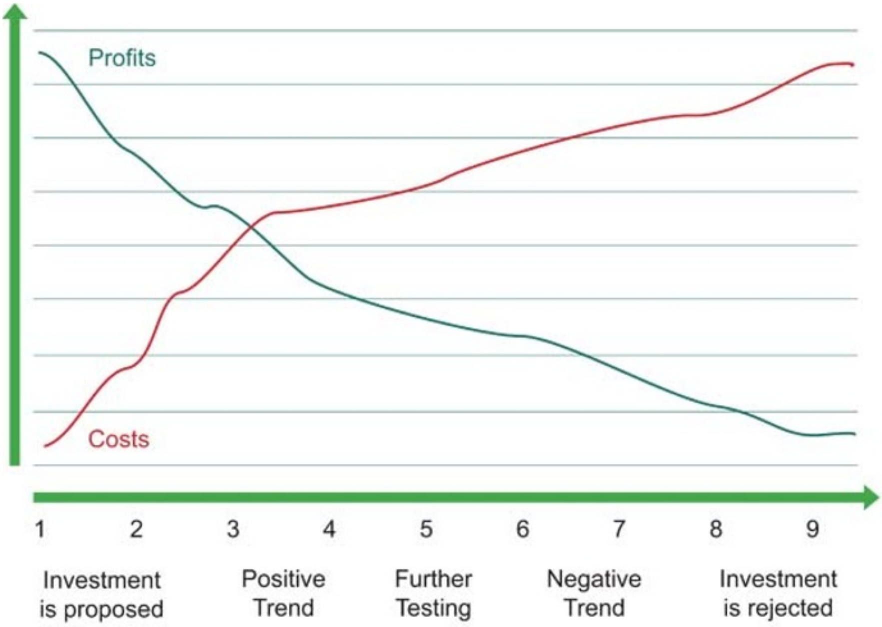

Fig. 3 Example for a NOWS chart

benefit graph shows a trend concerning accomplishing or refusing the investment (Fig. 3). It is recommended in the "Implementation" phase, that participants from the Interdisciplinary Investment Team directly accompany the process, so that the advice for the evaluation of strategies is directly incorporated into the transfer process. In the "Reflection" phase, the Interdisciplinary Investment Team appraises the experiences gathered during the process (planning, evaluation, implementation and supervision), and it issues recommendations on possible actions for the next implementations, or for the realization of subsequent training and further education processes.

4 Present Results

The following critical success factors respective opening the organizational borders as well as absorbing and integrating external knowledge were worked out based on a comprehensive literature search concerning SME, innovation management and Open Innovation. These factors are necessary to create one or more scenarios for the NOWS-workshops. Currently the project team interviews some of the project-related SME to corroborate the literature search. One enterprise is exemplified as the interviewed SME; in the following it will be called enterprise A. The company is a specialist in the three fields of IT support, individual software development as well as business process and IT consulting. The corporation has 10 employees and has references from the last 21 years. It has no R&D-department; rather it researches on behalf of its clients in Germany. It is important to mention that market fluctuations directly effect fluctuations within the enterprise, because the integration in a corporate group as a buffer doesn't exist. These are the central topics of the interview guide, each focusing the (open) innovation management:

- Description of activities concerning the integration of external knowledge within the innovation process
- Strategies and culture
- Operational and organizational structure
- Methods and tools
- The staff's competences and attitudes.

It has to be pointed out that there is no clear distinction between the following factors. The culture of an enterprise is for example affected by its internal communication. Furthermore the single success factors alone aren't essential for the success of Open Innovation-measures but their combination is.

Due to the literature search the entrepreneur is classified as a key personality and therefore as a success factor in SME. He would develop Open Innovation-measures but just if he is convinced that this strategy of innovation is successful. Hence the entrepreneur as a leader should be sensitive both for internal as well as external signals. He has to be able and willing to absorb business relevant information. Also the information has to be separated in the ones which are important for the day-to-day business and those which are relevant for the future business. Also this information has to be ranked concerning their importance [Ber89]. Furthermore being open for the future is a crucial factor concerning an innovation-supporting leadership. The adaptability of the entrepreneur is one of the most important requirements to classify him or her as a success factor.

Most innovations are the outcome of systemic and strategic plans [Spä10]. For this reason the most innovative SME in Germany make a note of their innovation strategies, reveal it to their employees and discuss it periodically [Spä10]. Another important aspect is the active encouragement of the team spirit. This could be achieved by an incentive system [Sch10]. It could be summarized that the Open Innovation-approach has to be supported by the SME's entrepreneur. This aspect was verified in one of the first interviews within the project-related committee. The director of the interviewed enterprise A told us that developing and challenging the innovation activities by the entrepreneur is indispensable (Interview, 14.02.2011).

According to the literature the innovative working climate is another critical success factor. In 2009 for example the enterprise Harro Höflinger Verpackungsmaschinen GmbH was nominated as the innovator of the year [Spä09]. This SME got the most points because of its innovative working climate (amongst others). The atmosphere there is characterized by the direct contact between the employees and the costumers. Hence a distinctive sense of responsibility concerning the employees is fixed in this SME [Spä09]. Very important is the participation and empowerment of the employees by allowing them to submit their own proposals. By analyzing techni-

cal and product-related processes as a team, the employees and the costumers work already in early phases of the innovation process (based on Lead-User workshops) together. Doing this they reduce the risks and adopt the products successful in the market [Spä09]. This example intensifies the assumption that a motivating innovative climate could be characterized as a success factor concerning Open Innovation in SME. The director of the interviewed enterprise A describes the organizational culture of his SME as an open one. The SME's external partners for example are allowed to join the internal meetings. Very important is the fact that every employee accepts that the external help is part of the performance and the value chain. From the director's point of view this culture encourages the absorption and integration of external knowledge (Interview, 14.02.2011).
Another success factor is a flat hierarchy. This becomes apparent by the SME Spreadshirt:

> Flat hierarchies, a lot of space for creativity and an individual influence quicken the ideas, which make Spreadshirt so successful. [Spr10]

These facts were confirmed in the interview with enterprise A (Interview, 14.02.2011).

5 Conclusion and Forecast

Until now there didn't exist any approaches concerning the controlling of Open Innovation-measures, especially for SME. Some of the existing approaches are classified as important substructures for following research projects but they do not comply with the control instrument requirements to act as a decision support for SME. Hence the research project "Invoice" has to develop an instrument to control Open Innovation-methods with regard to secure both the effectiveness and the efficiency of Open Innovation in SME. The first part of an integrated instrument to control Open Innovation-methods should be based on the method of the Value Oriented Cost-Effectiveness Estimation (NOWS) by Weydandt [Wey00]. This method will be used and refined in workshops with SME of different industries. The costs and benefits of different Open Innovation-methods (for example lead-user-method, innovation platforms or ideas competitions) will be measured by the employees, to conduct an ex-ante cost-effectiveness estimation of the respective Open Innovation-measurement. Within these workshops two graphs will visualize a first trend, if an Open Innovation-investment is worthwhile or not. Furthermore the program shows it's users until which point this investment would be worthwhile. Referring to these workshops a controlling concept concerning the planning, regulating and controlling of the whole Open Innovation-process will be developed. Within an integrated performance measurement a tool will be developed, which will be able to eliminate and monitor performance indicators of Open Innovation-measurements. A special challenge of this integrated performance measurement is the development of key figures which could map all the perspectives inside the innovation process as well as the integration of external knowledge into the entrepreneurial value chain.

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Achieving IT Security in a Telematic Rescue Assistance System

Matthias Müller, Daniel Schilberg, Sabina Jeschke

Abstract Many of the main causes of death such as heart attack and stroke usually strike outside of hospitals. Therefore patient outcome depends to a large extent on the quality of preclinical care. In order to improve it, Telematic Rescue Assistance Systems (TRAS) are being developed. They transmit vital signs, audio and sometimes video data from the rescue team to an emergency physician at a remote site, thus enabling this specialist to assist in diagnosis and treatment. Not only is specialist expertise brought to the emergency site, but also time to definite treatment is reduced, as specialists are involved earlier and hospitals can be informed in advance about incoming patients. The proper functioning of such systems depends on the correct handling of highly sensitive patient data. While there are numerous methodologies for achieving IT security for large organizations, none exists for small distributed medical systems such as TRAS. After comparing several methodologies, the IT baseline protection methodology [Sec08b] was chosen for its ability to prescribe specific IT security measures and applied to a TRAS currently in development in Aachen.

Key words: IT Security, Telematic Rescue Assistance System, Emergency Medical Services

1 Introduction

In preclinical emergency medicine there frequently is a lack of timely medical expertise at the emergency site. Unlike many other countries in Germany, the Emergency Medical Services (EMS) employ emergency physicians who travel to the patient's location. The number of missions involving EMS physicians has more than

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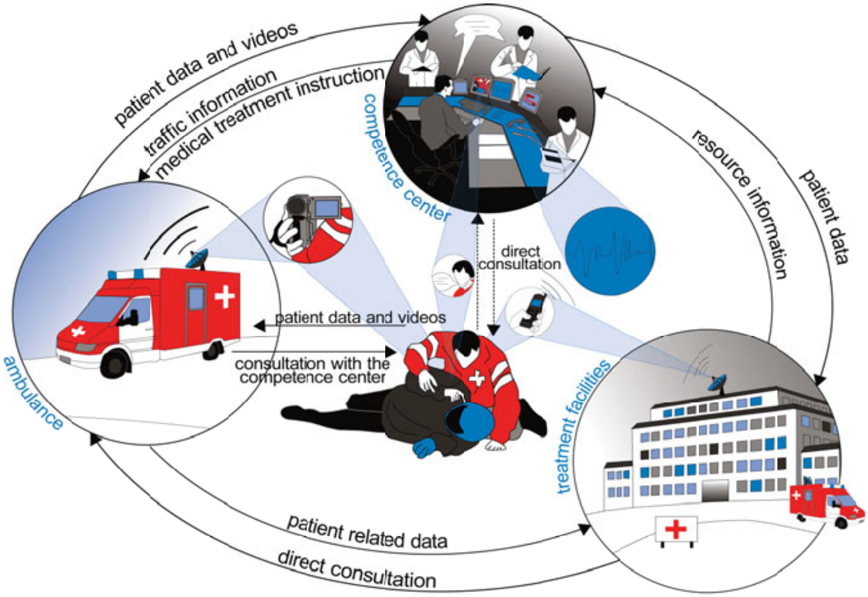

Fig. 1 An example of a Telematic Rescue Assistance System

doubled since 1990 [SBB04]. Unfortunately, this increase in demand was accompanied by a decrease in the number of physicians available [Mar08], thus further aggravating the situation. Not only are EMS physicians often sent out although this is not really indicated, but when their presence is indicated e.g. for decision-making, their manual abilities are needed in less then 15% of all missions [SBR+09]. Assuming that they received all relevant information, diagnosis and treatment could be decided at another location than the emergency site.

As shown in Fig. 1, Telematic Rescue Assistance Systems (TRAS) deliver patient information such as vital signs, audio and video data instantly to any relevant institution. Shortening the time between an emergency incident and definite treatment improves patient outcome, e.g. in heart attack or stroke [HMG03]. Also, the EMS physician does not lose time shuttling between ambulance station, emergency site and hospital in cases in which his physical presence is actually not needed. The benefits of TRAS are greatest in rural areas where EMS are sparse and large distances make traveling to the patient time-consuming.

In Aachen, Germany, researchers from the ZLW/IMA at RWTH Aachen University and the University Hospital Aachen, along with the engineers from P3 communications and Philips Healthcare, are developing a TRAS in the Med-on-@ix (medonaix.de) project. Their aim is to give an EMS physician at a remote site, the Competence Center (CompC), all the data needed to make timely informed decisions on diagnosis and treatment [PGH09]. Various vital signs, audio, photo, video data are transferred by a portable solution directly from the patient's location.

Similar to other distributed systems, risks are often found in recently developed components that have not been time proven [MPH09]. In TRAS the major novelty of the system lies in the ways existing IT components are integrated and made to work together. Therefore patient treatment in TRAS depends more on IT than in common EMS. Like other areas IT security is subject to a limitation of available resources. Therefore an approach needs to be chosen that allows resources to be spent as effectively as possible, while still ensuring the security of patient data. TRAS consist of several components that are connected to one another, using mostly wireless technologies. The majority of the system functionalities e.g. the visualization of vital signs are not provided by a single component, but by the successful combination of several components at the emergency site, ambulance and CompC. As the system becomes more elaborate, the attainment of IT security becomes more difficult.

In Sect. 2, different approaches for achieving IT security in TRAS are examined and one is chosen. In Sect. 3, the structure of the TRAS Med-on-@ix, including its IT assets and applications, is analyzed. In Sect. 4, security needs are identified and the protection requirements are gathered. Safeguards are determined using modules provided by IT baseline protection methodology in Sect. 5. Since IT security is subject to changes in technology as well as to the specific needs of a system, it needs to be reviewed periodically. That process is laid out in Sect. 6. This paper closes with a conclusion in Sect. 7.

2 Choosing a Methodology

Currently, no methodology for the establishment of IT security exists for TRAS. TRAS are being developed by research consortia, (e.g. DREAMS [SDW+00], StrokeNet [SGK+08], Stroke Angel [ZRM+08]) and small and medium enterprises (e.g. SHL telemedicine, ER-Link, Ortivus). They publish mostly clinical results. Regarding IT security only single measures are mentioned rather than a methodology. Ortivus [PBC+03] recognized the need for guarding against malicious code and acquired an IT security product for its telemedicine device [Hoe09]. SHL telemedicine [RMS+09] merely states that it follows “generally accepted industry standards” and that it utilizes “secure server software SSL” [tel10].

Hitherto, no methodology has been designed for small medical systems such as TRAS. There are several approaches for big organizations, yet usually they are defined in abstract terms in order to not subject them to technological change. The methodologies Common Criteria, the ISO 27000 standards family, COBIT and IT baseline protection are examined in more detail.

Common Criteria is a standard for the certification of IT security, which is described in ISO 15408. It aims to specify IT security, so that buyers can easily state requirements, vendors can work towards fulfilling them and independent third parties can evaluate the fulfillment of them. Unfortunately, it is very generic and gives little specific advice on what steps to take to achieve IT security. It also has been criticized as being too costly and too focused on paperwork [Jac07].

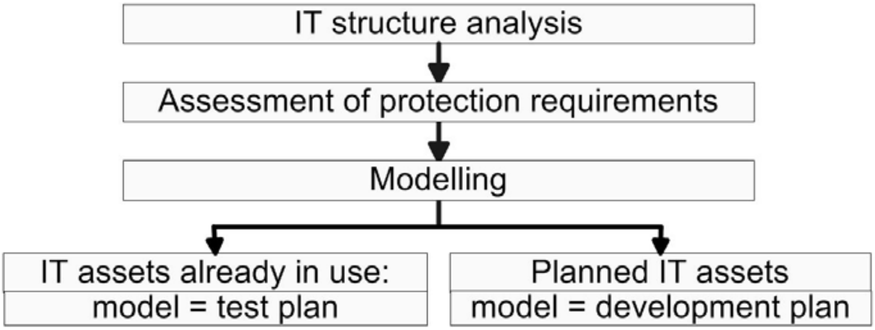

Fig. 2 Creation of an IT security concept according to IT baseline protection [Sec05]

The ISO 27000 standards family tries to foster best practices in information security management, similar to what the ISO 9000 standards family does for quality management. ISO 27002 focuses mainly on the steps necessary to establish a functioning security management system and anchor it in the organization [Sec08b]. ISO 27001 allows the certification of IT security standards comparable to the one of ISO 9000 for processes. The ISO 27000 family contains important aspects of successful IT security management, but is also very generic and not descriptive. ISO 27799 adapts ISO 27002 to the medical field. Unfortunately, like ISO 27002, it is very generic and offers little practical advice. Annex A of ISO 27799 lists common threats in the medical field, which also apply to TRAS, such as the difficulty of keeping outsiders such as patients from accessing areas where medical infrastructure is located.

Control Objectives for Information and related Technology (COBIT) aims to align IT governance with the main business processes [RYC04]. It encompasses many fields, of which IT security is a small section [VS05]. Its IT security part is based on ISO 27002, and since the goal is overall IT governance it focuses especially on control and measuring points. It is aimed at large corporations and, like ISO 27002, it is too general.

The IT baseline protection [Sec08b, Sec08a, Sec08c], developed by the German Federal Office for Information Security, specifies the general ISO 27000 IT security standard family further and gives practical advice in its application. Also, it provides practical steps toward the certification to different security levels including ISO 27001. It is a reference work containing recommendations for secure handling of information and IT in a wide range of industries. Companies such as Daimler, Siemens, BASF and Deutsche Lufthansa apply it to meet safety requirements for IT as well as local health services like hospitals, medical practice and health insurance companies [Sec09]. The approach is depicted in Fig. 2. First, the existing IT infrastructure is analyzed. The main IT assets and their locations are listed as well as the main applications they provide. In order to assess security needs, the main applications are classified according to criticality to business success. Then, they are mapped to the IT assets they use. If an application such as the visualization of vital signs is critical, then the computer on which the vital signs are displayed and the room where it is located at are also critical. The IT system is modeled using IT baseline protection modules [Sec05]. These modules describe the most common threats and their safeguards for each component, e.g. laptops or servers. Based on these modules a test plan and a development plan for the system are created.

Whereas ISO 27000, Common Criteria and COBIT deal mainly with the setting up and running of an IT security management system, IT baseline protection gives specific details of how to achieve IT security. It also recommends additional safeguards that can be taken in order to establish a higher level of IT security. For these reasons the methodology used in this paper follows the one set out by IT baseline protection.

3 IT Structure Analysis

In accordance with the IT baseline protection methodology [Sec08b], an IT structure analysis is carried out. First, the hardware used in the system is surveyed. In order to do so, a list of all network components is compiled. It includes relevant information such as a unique identifier, a description, the platform they run on, the site, who they are connected with, the user and the technology employed. The list for the TRAS Med-on-@ix is given in Table 1. The components include medical devices such as the electronic stethoscope and the patient monitor, as well as the communication unit. They are distributed across the emergency site, the ambulance and the CompC. Since most of the hardware is standardized, it can be gathered quite easily. After identifying the hardware components, a list of locations and their IT assets is compiled. This holistic approach according to the FSI layer model [Sec05] is necessary because administrators often treat IT security in terms of security gadgets such as firewalls and neglect the danger of granting outsiders access to the rooms, where important hardware is located. In medicine it is especially difficult to keep outsiders such as patients and their relatives from rooms and devices with critical patient information [Sta08].

Vital organizational processes such as accounting depend on the proper functioning of IT applications. In the case of TRAS these processes include videos, photos, audio, vital parameters and other applications that the remote EMS physician needs in order to make a sound decision on patient diagnosis and treatment. An excerpt of the applications of a TRAS, the type of information they handle, their respective users and the IT systems they run on is given in Table 2.

Figure 3 shows the IT structure of the TRAS developed in Med-on-@ix. As can be seen, important IT security aspects have already been planned and implemented at an architectural level [MPH09, PGH09, PGH10]. Communication between the emergency site and the CompC is carried out via VPN in order to ensure the confidentiality and the integrity of patient data. An extra computer at the CompC provides the remote emergency physician with access to outside clinical databases.

Table 1 IT assets of the Tras Med-on-@ix

No	Description	Platform	Site	Connected with	User	Technology
T1	GSM audio device		Emergency site	CompC	EMS staff	GMS/UMTS, ISDN
PC1	Private Branch Exchange (PBX)	Linux	CompC	ISDN network, local VoIP	CompC staff	TETRA, ISDN, SIP/RTP
PC4	Communication unit 2	Linux	CompC (data center)	Internet, Local data center		Fiber connection to RWTH data center
PC7	Communication unit 1	Linux	Emergency site	Internet		UMTS, HSDPA, HSUPA, GPRS
PC8	Tablet PC	Windows XP	Emergency site	Communication unit 1	EMS staff	WLAN (WPA2)
M1	Electronic stethoscope		Emergency site	Communication unit 1	EMS staff	Bluetooth 2.0
KA1	Mobile video camera		Emergency site	Communication unit 1	EMS staff, remote EMS physician	WLAN (WPA2)
Ka2	MICU camera		MICU	Communication unit 1	EMS staff, remote EMS physician	WLAN (WPA2)
T2	Bluetooth headsets		Emergency site, CompC	Communication unit 1, 2	EMS/CompC staff	Bluetooth 2.0
M2	Patient monitor		Emergency site	Communication unit 1	EMS staff	WLAN (WPA2)
PC5	Remote EMS physician computer	Windows XP	CompC	Local data center	Remote EMS physician	LAN
PC6	TNA external computer	Windows XP	CompC	Internet	Remote EMS physician	LAN
PC2	Central server services	Linux	CompC (data center)	Local data center	Administrators	LAN
PC3	Web services	Linux	CompC (data center)	Local data center	Administrators	LAN
T3	Telephone		CompC	PBX	Remote EMS physician	
T4	Fax		CompC	PBX	Remote EMS physician	
Dr1	Printer		CompC	Remote EMS physician computer	Remote EMS physician	
Dr2	MICU printer		MICU	MICU Hub	EMS staff	LAN
PC2	User DB	Linux	CompC (data center)	Local data center		LAN
PC2	Mission DB	Linux	CompC (data center)	Local data center	Remote EMS physician	LAN
PC2	DB Med	Linux	CompC (data center)	Local data center	Remote EMS physician	LAN
PC2	Coverage DB	Linux	CompC (data center)	Local data center	Administrators	LAN

Table 2 Applications of Tras (Excerpt)

No.	Application	Type of information	User	IT system
Video and Photo				
A1	Video capturing	A/V	Remote EMS physician	Mobile/MICU camera
A2	Video transmission (live)	A/V	Remote EMS physician	Communication unit 1, 2, (PC7, PC4)
				(No suggestions) (PC1)
A3	Displaying videos	A/V	Remote EMS physician	Remote EMS physician computer (PC5)
A4	Remote control of camera	T	Remote EMS physician	Remote EMS physician computer (PC5)
A5	Photo capturing	A/V	Remote EMS physician	Digital camera
A6	Buffering photos	A/V	Remote EMS physician	Communication unit 1 (PC7)
A7	Transfer photos	A/V	Remote EMS physician	Communication unit 1, 2 (PC7, PC4),
				PBX (PC1)
A8	Displaying photos	A/V	Remote EMS physician	Remote EMS physician computer (PC5)
A9	Control of digital camera	T	EMS staff	Digital camera
A10	Archiving of video and photos	A/V		Mission DB (PC2)
Vital signs				
A17	Recording of vital signs	Pa	Remote EMS physician	Patient monitor
			EMS staff	
A18	Transmission of vital signs	Pa	Remote EMS physician	Communication unit 1, 2 (PC7, PC4),
			EMS staff	PBX (PC1)
A19	Display of vital parameters in CompC	Pa	Remote EMS physician	Remote EMS physician computer (PC5)
A20	Auscultation with stethoscope	Pa	Remote EMS physician, EMS staff	Electronic stethoscope
A21	Transfer of the stethoscope data	Pa	Remote EMS physician	Communication unit 1, 2 (PC7, PC4),
				PBX (PC1)
A22	Reproduction of stethoscope data	Pa	Remote EMS physician	Headset
A23	Archiving of vital signs	Pa		Mission DB (PC2)

Pa: Patient data, A/V: Audio/Video data, T: Technical Data

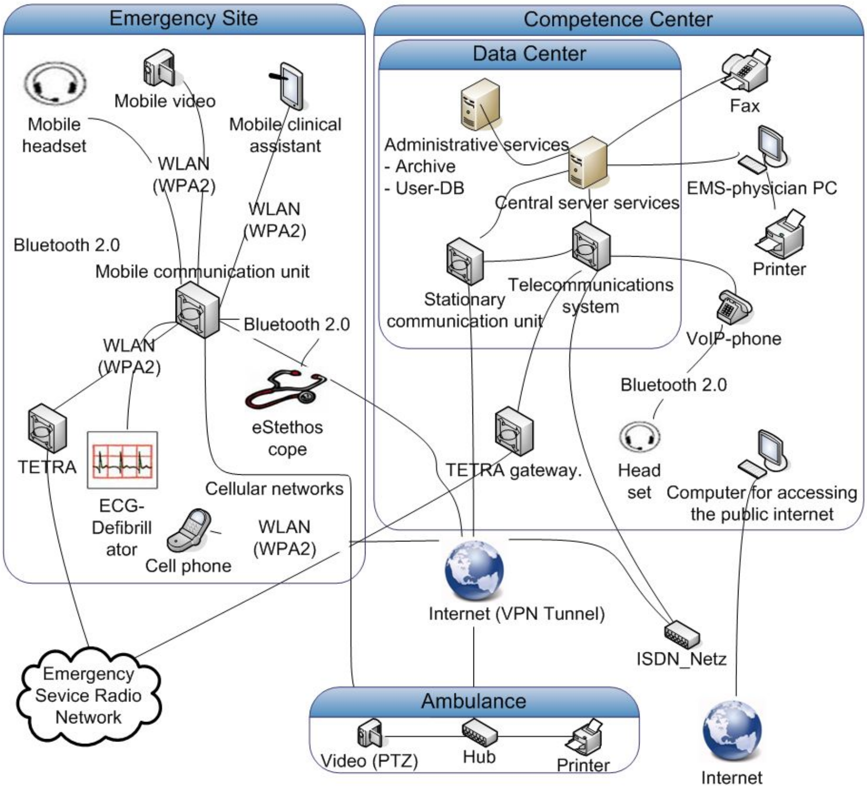

Fig. 3 The IT structure of the TRAS Med-on-@ix

4 Assessment of Protection Requirements

The IT protection required depends on the criticality of the applications to the organization. If an application is highly critical, then the IT security of the hardware it runs on is also highly critical and not everybody should have access to it. In order to assess the criticality of different applications, categories for assessing criticality have to be defined. These categories are defined qualitatively. A quantitative assessment would more often than not be cumbersome, inaccurate and time-consuming, while at the same time instilling a false sense of control [Sec08b]. The protection requirement categories for the TRAS Med-on-@ix are shown in Table 3.

The security level of different applications was examined by a survey of experts. These included EMS physicians and developers from both within and outside the project. Each expert individually assessed the security needs of the applications according to the following categories: legal violations, impairment of informational self-determination, impairment of personal integrity, impairment of work processes, negative internal and external effects and financial implications. Table 4 shows the results of the survey for video and photo applications. The median was used to

Table 3 Protection requirement categories

Low	Impairment is not likely
Normal	The effects of damages are limited and manageable
High	The effects of damages can be significant
Very high	The effects of damages can reach an existentially threatening catastrophic level including death

Table 4 Protection needs of videos and photos

	Aspects	Protection needs of videos and photos				
		Low	Normal	High	Very high	Sum
1	Violation of laws/regulations/contracts	0	4	2	3	9
2	Impairment of informational self-determination	0	4	3	2	9
3	Impairment of personal integrity	3	2	3	1	9
4	Impairment of work processes	0	3	5	0	8
5	Negative internal or external effects	0	3	4	2	9
6	Financial implications	3	2	2	2	9

Median (shaded cells: row 1 High; row 2 High; row 3 Normal; row 4 High; row 5 High; row 6 Normal)

aggregate what the experts thought. The IT security needs differ according to the aspects that are examined.

IT baseline protection proposes using the maximum principle: the highest IT security need of all aspects determines the overall security need of an application. For instance, as the security need is determined to be high for video and photo data from a legal standpoint, its overall security need is considered to be at least high.

Almost all the data that are captured, transmitted and visualized are patient data. The survey showed that at an aggregate level the IT protection required for this data are high, because of their confidentiality and their relevance to patient treatment. As a result, all IT assets that process them, which include all IT assets bar the computer of the EMS physician for external access, require a high IT security protection level. All locations contain IT assets that have a high IT security need and thus also require a high protection level.

5 Selection and Adaption of Security Measures

The aim is to establish a comprehensive checklist of the most common IT security threats and safeguards for the IT system without the hassle of going through a risk analysis for the most common threats. Also, a piecemeal approach, in which for example a top-notch firewall is combined with an operating system that is not updated regularly, is to be avoided. In order to achieve this, the system is modeled with modules that already describe threats and safeguards for the different IT components

Table 5 IT assets in Med-on-@ix and their respective modules

No.	Description	BSI module	Infrastructure module	Other module
T1	GSM audio device	B.3.404 Cell phone	B.2.10 Mobile workstation	B.1.5 Privacy policy (reason: personal data)
PC1	Private Branch Exchange (PBX)	B.3.401 PBX B.3.101 General server B.4.5 LAN connections of an IT system via ISDN	B.2.1 Building B.2.2 Electronical wiring B.2.3 Office	B.1.5 Privacy policy (reason: personal data) B.2.12 IT cabling B.4.6 WLAN
PC7	Communication unit 1	B.3.301 Security gateway (firewall) B.3.101 General server	B.2.10 Mobile workstation	B.1.5 Privacy policy (reason: personal data) B.4.6 WLAN
PC4	Communication unit 2	B.3.301 Security gateway (firewall) B.3.101 General server	B.2.1 Building B.2.2 Electronical wiring B.2.5 Data archive B.2.9 Data center B.3.302 Routers and switches	B.1.5 Privacy policy (reason: personal data) B.2.12 IT cabling
PC8	Tablet PCs	B.3.203 Laptop	B.2.10 Mobile workstation	B.1.5 Privacy policy (reason: personal data) B.4.6 WLAN
M1	Electronic stethoscope		B.2.10 Mobile workstation	B.1.5 Privacy policy (reason: personal data) B.4.6 WLAN
KA1	Mobile video camera		B.2.10 Mobile workstation	B.1.5 Privacy policy (reason: personal data) B.4.6 WLAN
Ka2	MICU camera		B.2.10 Mobile workstation	B.1.5 Privacy policy (reason: personal data) B.2.12 IT cabling
T2	Bluetooth headsets		B.2.10 Mobile workstation B.2.1 Building B.2.2 Electronical wiring B.2.3 Office	B.1.5 Privacy policy (reason: personal data) B.4.6 WLAN
M2	Patient monitor		B.2.10 Mobile workstation	B.1.5 Privacy policy (reason: personal data)
PC5	Remote EMS physician computer	B.3.201 General client B.5.3 E-mail	B.2.1 Building B.2.2 Electronical wiring B.2.3 Office	B.1.5 Privacy policy (reason: personal data) B.2.12 IT cabling
PC6	TNA external computer	B.3.208 Internet PC	B.2.1 Building B.2.2 Electronical wiring B.2.3 Office	B.1.5 Privacy policy (reason: personal data) B.2.12 IT cabling

[Sec05], Module B.2.10, for example, describes a mobile workspace. Threats are mentioned in order to raise awareness where possible pitfalls lie, e.g. for mobile workspaces one threat is the inappropriate handling of passwords (Threat T.3.43). Safeguards for the component are listed, e.g. the observance of rules concerning workstations and working environments (safeguard S.2.136).

The modules are classified according to the parts of system they describe: universal application aspects, infrastructure (e.g. B.2.10), IT systems, networks and IT applications. Universal application aspects apply to the system as a whole, e.g. the IT security process itself, organization and personnel, and have to be applied once to the whole system. Then, IT components are modeled individually. Threats are classified according to their origin, e.g. T.3.43 belongs to category T3 human failure. Safeguards, meanwhile, are classified according to the moment when they should be implemented, for instance during operation (e.g. S.2.136). Based on the IT structure analysis and the resulting security needs, the TRAS Med-on-@ix was modeled (see Table 5). The IT baseline protection modules are at the heart of its IT security concept.

6 Information Security Process

IT security is not established once, but it is subject to change, and thus the IT security concept has to be updated periodically [Sec08b, Sec08a, Sec08c, Sta05]. Exploits are discovered by intruders and closed by software vendors continuously. Also, IT infrastructure is subject to change as new devices are bought and sold and new applications used. Additionally, one of the most important steps toward achieving an adequate level of IT security is not the creation of an IT security concept itself, but rather initiating and continuing an IT security management process. This includes the setting up of an IT security management, which helps to ensure that the creation or update of an IT security concept, the implementation of missing safeguards and the maintenance in ongoing operations are carried out properly. Also, it has to control whether existing defined measures are being applied correctly, whether measures are still adequate and whether the structure of the system has changed.

Often it is not possible to apply all measures at once. Some guidance is given in the prioritization by the BSI itself, which can help to choose the measures to be implemented. The security of the information that is vital to an organization is the responsibility of the top management of an organization. Yet it has been proven helpful to name a person responsible for the operational aspects of IT security.

7 Conclusion

IT baseline protection allowed achieving a checklist of IT security safeguards for the TRAS Med-on-@ix, as well as its components, rapidly. Due to its systematic approach, all main applications and IT assets were identified and safeguards were defined for them. Not all IT security safeguards recommended by IT baseline protection were implemented. The requirements are quite exhaustive, and the security level it aims to attain as well as its costs can be high. Therefore it is helpful to start with the requirements marked A at first and then proceed to the ones classified as B. IT security costs resources and the decision of whether or not to take certain precautions has to be made on an individual basis. It is not advisable to apply all safeguards of the methodology blindly. For some parts, such as the electronic stethoscope, no IT baseline protection modules existed. Modules such as the Bluetooth headset can be used for such components. Many of its safeguards such as data encryption are applicable, although it was not specifically developed for the medical field. Further research may include whether the specific threats of the medical field such the ones pointed out in Annex A of ISO 27799 can be applied to the security concept developed for TRAS. The research presented in this paper could be used as the basis for a methodology to reduce IT security risk as well as hardware and software risk in the development of TRAS, helping to achieve an overall security level early in the design stages of a TRAS.

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Reducing Hardware Risks in the Development of Telematic Rescue Assistance Systems: A Methodology

Matthias Müller, Patrick Loijens, Daniel Schilberg, Sabina Jeschke

Abstract In developed countries many of the main causes of death such as heart attack and stroke usually strike outside of hospitals. Therefore patient outcome depends to a large extent on the quality of preclinical care. In order to improve it, Telematic Rescue Assistance Systems (TRAS) are being developed. They transmit vital signs, audio and sometimes video data from the rescue team to an emergency physician at a remote site, thus enabling this specialist to assist in diagnosis and treatment. Not only is specialist expertise brought to the emergency site, but also time to definite treatment is reduced, as specialists are involved earlier and hospitals are informed in advance about incoming patients. Due to their use in emergencies, risks to the proper functioning of TRAS hardware have to be kept as low as possible. Adequate methods for risk assessment have to be chosen, since the use of an inadequate method can result in a cumbersome resource-intensive process, while at the same time major risks are being overlooked. This paper proposes a methodology for reducing hardware risks in the development of TRAS.

Key words: Remote Diagnostics and Care, Ehealth, Mhealth Services and Portals, IT Services and Technologies for Rural and Poor Areas

1 Introduction

In preclinical emergency medicine there frequently is a lack of timely medical expertise at the emergency site. Unlike many other countries in Germany the Emergency Medical Services (EMS) employ emergency physicians who travel to the patient location. Due to an increase in both the total number of EMS missions and the share involving EMS physicians, the number of missions of EMS physicians has

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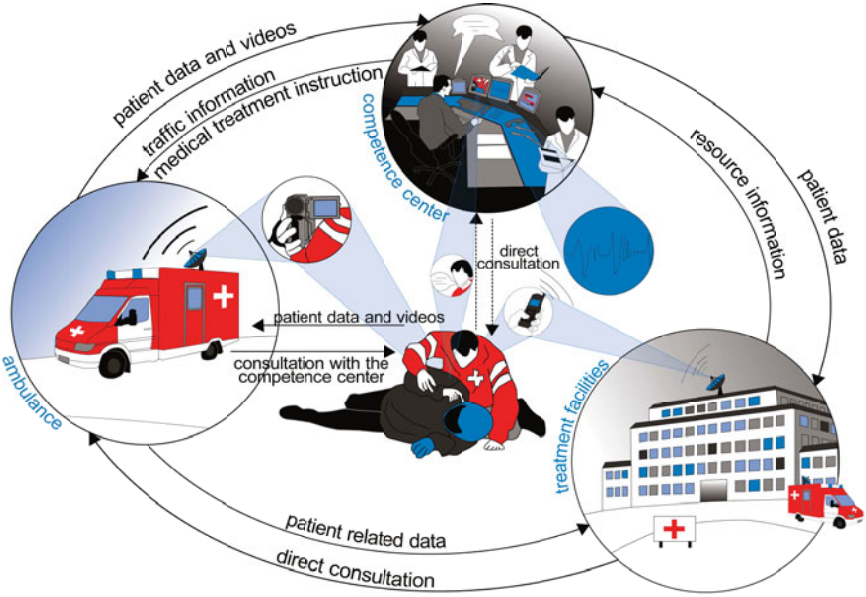

Fig. 1 An example of a Telematic Rescue Assistance System

more than doubled since 1990 [SBB04]. Unfortunately, the increase in demand was accompanied by a decrease in the number of physicians available [Mar08], thus further aggravating the situation. Not only are EMS physicians often sent out although this is not really indicated, when their presence is indicated e.g. for decision-making, their manual abilities are needed in less then 15 % of all missions [SBR+09]. Provided they received all relevant information, diagnosis and treatment could be decided at another location than the emergency site.

As is shown in Fig. 1 TRAS can deliver patient information such as vital signs, audio and video data instantly to any relevant institution. Shortening the time between an emergency incident and definite treatment improves patient outcome, e.g. in heart attack or stroke [GdLA04]. Also, the EMS physician does not lose time shuttling between ambulance station, emergency site and hospital in cases where his physical presence is actually not needed. The benefits of TRAS are greatest in rural areas where EMS are sparse and distances make travelling to the patient time-consuming.

Technical risks of TRAS, including hardware, software and IT security risks, have to be kept as low as possible – ideally during the development process [MPH09]. TRAS are used in the physically rough field of emergency medicine. Hence, reliable system hardware is the physical basis of TRAS. An abundance of different methods for the identification of hardware risks is available, each method associated with its own advantages and drawbacks. Choosing an ineffective method is a waste of resources and leads to a cumbersome process. Even worse, it instills a false sense of security, because major risks are being overlooked [Com03]. Using a feasible methodology has the benefit of applying methods proven effective leading thus to higher product quality. Up till now no methodology to reduce hardware risks for TRAS existed. Therefore it was unclear which of the many existing methods was suited to analyze them. In this paper we propose a methodology for reducing hardware risks in the development of TRAS.

Firstly, existing methods are examined and classified according to their suitability to reduce risks in different circumstances (Sect. 2). Next, common characteristics of TRAS are described and the span of methods is narrowed down to the ones suiting TRAS (Sect. 3). The methodology for TRAS is then applied to a currently developed system (Sect. 4).

2 A General Methodology for Technical Systems

At the beginning the objective of the risk analysis and the parameters of the system examined are established. The objective may range from a swift cursory estimation of risks to a thorough, detailed and therefore lengthy analysis of the system. The parameters of analysis such as the dependence between the failure rates of the subsystems are determined. Then based on these the methods for risk analysis are selected and applied to identify risks. Finally risks are evaluated and measures for their reduction are determined.

The principal methods to reduce technical risk can be classified as either deductive or inductive. A deductive method explores possible causes of an undesired effect e.g. system failure, whereas an inductive method studies the effects of an undesired cause e.g. component failure. In theory both inductive and deductive methods applied individually should successfully identify risks. In practice they complement each other by examining the system from different perspectives. Therefore to reduce hardware risks, as a rule a mix of inductive and deductive methods is used [Com03].

Based on the work from Biegert [Bie03] common methods are classified according to their ability to identify risks with different system characteristics and at different stages of the development process. The methods are classified according to their approach, their objective, their risk assessment, their underlying model, their purpose and their field of application (Table 1).

Deductive methods include Fault Tree Analysis (FTA), Reliability Block Diagrams (RBD), Checklists, Technique for Human Error Rate Prediction (THERP), Petri nets and formal methods. FTA is widely used for identifying the causes for a chosen top-event e.g. system failure [Com06b]. RBDs help to model failure behavior of system components and can serve as input for a FTA [Com06c]. A simple way to identify known hazards is provided by checklists, which are mainly based on experience, either from previous analysis or when damage occurred. THERP, coming from the field of Human Reliability Analysis, aims at integrating the impact of human error into a quantitative analysis [SG83]. Markov Analysis is used to model changes between different system states [Com06d], whereas Petri nets are used to

Table 1 Classification of Risk Reduction Methods

	FTA	Reliability Block Diagram	Checklists	THERP	Markov Analysis	Petri nets	Formal methods	FMEA / FMECA	HACCP	ETA	PHA	Prediction of Failure Rate	HAZOP	SQMA
Approach														
Inductive	-	-	-	-	-	-	-	X	X	X	X	X	X	X
Deductive	X	X	X	X	X	X	X	-	-	-	-	-	-	-
Brainstorming process	X	-	X	X	-	-	-	X	X	X	X	-	X	-
Model-based analysis	-	X	-	-	X	X	X	-	-	-	-	-	-	X
Objective of analysis														
Investigation of hazardous operating states	-	-	-	X	X	X	-	-	X	X	X	-	X	X
Investigation of hazardous events	X	-	-	X	X	X	-	X	X	-	X	-	X	-
Investigation of critical system elements	-	X	-	-	X	X	-	X	X	-	X	X	-	X
Investigation of priorities	-	-	-	-	-	-	-	X	X	-	X	-	-	-
Verification against safety requirements	X	X	X	-	X	X	X	X	X	-	-	-	-	-
Verification against reliability targets	X	X	-	-	X	X	X	-	-	-	-	X	-	-
Identification of single errors	X	X	X	X	X	X	-	X	X	X	X	X	X	X
Identification of multiple errors	X	-	-	-	X	X	-	-	-	-	-	-	-	X
Study of event sequences (single event)	X	-	-	X	X	X	-	X	X	X	-	-	X	X
Study of event sequences (dependent)	-	-	-	-	X	X	-	-	-	X	-	-	-	-
Study of event sequences (independent)	X	-	-	-	X	X	-	-	-	-	-	-	-	X
Risk assessment														
Qualitative	X	X	X	X	X	X	-	X	X	X	X	X	X	X
Quantitative	X	X	X	X	X	X	X	X	-	X	-	X	-	-
- Probability assessment	X	X	-	X	X	X	-	X	-	X	-	X	-	-
- Risk assessment	-	-	-	-	-	-	-	X	-	-	-	-	-	-
- Reliability assessment	X	X	-	-	X	X	-	-	-	X	-	X	-	-
Model used														
Tree (graph)	X	X	-	X	-	-	-	X	X	X	-	-	X	-
State machine	-	-	-	-	X	X	X	-	-	-	-	-	-	-
Qualitative modeling	-	-	-	-	-	-	-	-	-	-	-	-	-	X
Text tables	-	-	X	X	-	-	X	X	X	-	X	X	X	X
Purpose of analysis														
Result representation	X	-	-	X	X	X	-	X	X	X	X	X	-	-
Quantitative analysis	X	X	-	X	X	X	-	X	-	X	-	X	-	-
Performing the analysis	-	X	-	-	X	X	X	-	-	-	-	-	-	X
Representation of temporal behavior	X	-	-	-	X	X	-	X	-	-	-	-	-	-
Field of application														
Technical system	+	0	+	-	+	+	-	+	+	+	+	+	+	+
Human operator intervention	+	-	+	+	0	0	-	0	+	0	0	-	+	0
Hardware	+	+	+	-	+	+	+	+	0	+	+	+	+	+
Software	+	0	+	-	+	+	+	+	+	+	0	-	+	-
Complex system	+	0	+	+	+	+	-	0	0	0	0	-	+	0
Novel system	+	0	-	0	+	+	+	0	0	0	+	+	+	0
Early stages of development	+	+	+	+	0	0	+	+	+	+	+	+	+	+
Iterative process	+	+	+	+	+	+	-	+	+	+	+	+	+	+
X: Applicable	+: Primary field of application													
-: Not applicable / strongly discouraged	0: Applicable with major limitations													
	-: Not suitable for field of application													

model a system using the model elements places and transformations [Mur89]. Both deduce future system behavior based on their models. Formal methods describe the system with mathematical formulas [Bie03], yet they are very complex and thus prone to errors.

Inductive methods include Failure Mode and Effects Analysis (FMEA), Hazard Analysis Critical Control Point (HACCP), Event Tree Analysis (ETA), Preliminary Hazard Analysis (PHA), prediction of failure rate, Hazard and Operability study (HAZOP) and Situation-based Qualitative Modelling and Analysis (SQMA). FMEA is widely used for examining how failure modes of components affect overall system functionality [Com06a]. Based on FMEA, HACCP has since been widely adopted as a safety standard in the food industry [fS01]. ETA facilitates the analysis of event chains [oD00] and may serve to complement FTA and FMEA. PHA is employed at an early design stage to analyze the system at a high level [fNe85]. Failure rates of new electrical components may be predicted based on known failure rates of existing ones [Com96]. HAZOP, originally invented for the chemical industry, is used to identify and evaluate problems in processes [Com01]. SQMA analyze hazards on the basis of a qualitative model of the system [Lau96].

3 A Methodology for Telematic Rescue Assistance Systems

The general methodology presented in Sect. 2 needs to be specified further in order to fit TRAS. Firstly the objective of analysis is set and common properties of TRAS are characterized along Table 1. Then the number of methods is narrowed down. Thus a specific methodology for TRAS is provided.

In the development phase risks are mainly reduced by lowering the failure rate of subsystems and components. The principal failures in the context of TRAS are damage to the patient, the personnel, the technical system or its surroundings. The methodology should be able to check for compliance with safety requirements. TRAS are complex, as they consist of many diverse subsystems and are intricate in both structure and behavior. The hardware components are distributed on the emergency site, the ambulance, the server site and the competence center. The system applies existing components in a field and a combination they were originally not developed for and is thus novel. Due to its novelty the system is subject to frequent changes during the early stages of the development process, and if models are used they have to be modified very often. As model-based methods depend on a more or less stable model, brainstorming-based methods are preferred to model-based ones. There is a considerable independence between components, since the architecture is modular [PGH09]. As a result the methods must be able to identify hardware risks in complex, novel systems early on in the development process.

In Table 2 the governing characteristics and the methods that do not comply with them are colored in grey. The methods not directly applicable to TRAS are ETA, THERP, SQMA, formal methods, failure rate prediction, RBD, and Checklists. Markov analysis and Petri nets would be suitable according to the criteria, but are model-based and thus too cumbersome to be applied early on in the development process.

Thus the methods adequate for risk identification are HAZOP, FMEA, FTA, PHA and HACCP. Of these only FTA is an inductive method. ETA, RBD and checklists may still be used as add-ons. Often an FTA is combined with an ETA to identify

Table 2 Risk Reduction Methods According to Their Suitability for TRAS

	FTA	Reliability Block Diagram	Checklists	THERP	MarkovAnalysis	Petri nets	Formal methods	FMEA / FMECA	HACCP	ETA	PHA	Prediction of Failure Rate	HAZOP	SQMA
Approach														
Inductive	-	-	-	-	-	-	-	X	X	X	X	X	X	X
Deductive	X	X	X	X	X	X	X	-	-	-	-	-	-	-
Objective of analysis														
Investigation of hazardous operating states	-	-	-	X	X	X	-	-	X	X	X	-	X	X
Investigation of hazardous events	X	-	-	X	X	X	-	X	X	-	X	-	X	-
Investigation of critical system elements	-	X	-	-	X	X	-	X	X	-	X	X	-	X
Investigation of priorities	-	-	-	-	-	-	-	X	X	-	X	-	-	-
Verification against safety requirements	X	X	X	-	X	X	X	X	X	-	-	-	-	-
Verification against reliability targets	X	X	-	-	X	X	X	-	-	-	-	X	-	-
Identification of single errors	X	X	X	X	X	X	-	X	X	X	X	X	X	X
Identification of multiple errors	X	-	-	-	X	X	-	-	-	-	-	-	-	X
Study of event sequences (single event)	X	-	-	X	X	X	-	X	X	X	-	-	X	X
Study of event sequences (dependent)	-	-	-	-	X	X	-	-	-	X	-	-	-	-
Study of event sequences (independent)	X	-	-	-	X	X	-	-	-	-	-	-	-	X
Field of application														
Technical system	+	0	+	-	+	+	-	+	+	+	+	+	+	+
Human operator intervention	+	-	+	+	0	0	-	0	+	0	0	-	+	0
Hardware	+	+	+	-	+	+	+	+	0	+	+	+	+	+
Software	+	0	+	-	+	+	+	+	+	+	0	-	+	-
Complex system	+	0	+	+	+	+	-	0	0	0	0	-	+	0
Novel system	+	0	-	0	+	+	+	0	0	0	+	+	+	0
Early stages of development	+	+	+	+	0	0	+	+	+	+	+	+	+	+
Iterative process	+	+	+	+	+	+	-	+	+	+	+	+	+	+
X: Applicable	+: Primary field of application													
-: Not applicable / strongly discouraged	0: Applicable with major limitations													
	-: Not suitable for field of application													

different failure modes. In order to acquire reliability data as input for FTA and FMEA RBDs may be used. Often checklists are already employed in emergency medicine.

We propose the following combination of methods to identify risks in developing stages of TRAS: PHA, FTA and ETA. Firstly a PHA identifies areas of major risks to obtain an overview of the system. Based on these findings an FTA is performed, with the worst case being the complete failure of a critical component. For specific time-sensitive risks such as network availability an ETA is carried out. Measures for reducing technical risks are specified.

The success of risk reduction depends to a large degree on gathering expert opinion. These experts include emergency physicians, paramedics, project leaders, telecommunication experts and manufacturers of medical devices. Qualitative information is usually collected in workshops with experts. Quantitative information may be obtained by measuring network coverage and network availability, by comparing existing components with the newly developed ones and by retrospective studies of past emergency missions.

4 Application of the Med-on-@ix System

The TRAS methodology is adapted to the application example Med-on-@ix [SBR+09]. In Aachen, Germany, researchers from the Institute of Information Management at the RWTH Aachen University and the University Hospital Aachen along with the engineers from P3 communications and Philips Healthcare are developing a TRAS in the Med-on-@ix project (www.medonaix.de). Their aim is to provide an EMS physician at a remote site with the data needed to make timely, informed decisions on diagnosis and treatment [PGH10]. The basic structure of the Med-on-@ix system is shown in Fig. 2.

Audio and video signals as well as vital signs are captured at the emergency site and in the ambulance and sent to an experienced emergency physician at a remote location. Data is transmitted locally via WLAN and Bluetooth, over larger distances via 2G and 3G wireless networks as well as via Terrestrial Trunked Radio (TETRA). A tablet PC provides the user interface for documentation, visualization of vital signs and system control. Vital signs, photos, audio and video data are displayed at the competence center.

The combination of PHA, FTA and ETA was applied to identify risks in the development stage of Med-on-@ix. During the PHA failure modes were identified and their probability and their potential impact evaluated. This evaluation was carried out qualitatively using five categories with the probability ranging from improbable to highly probable and the potential impact ranging from negligible to catastrophic. An inhomogeneous prioritization according to Mil-Std-882 [fNe85] was used to prioritize risks. The audio connection, the communication unit and the tablet PC used for all controls as well as data entry were identified as critical components. An excerpt of the results of the PHA is shown in Table 3.

The PHA helped to identify numerous hazards and failure modes. The use of a moderator proved to be the key for a successful identification of hazards, striking the balance between letting participants focus on the details of a particular hazard and keeping the team from veering to far of its original objective. In order to achieve this, the moderator refrained from participating actively in the brainstorming process.

Based on the PHA the FTA was performed. In order to gather further information and consider more perspectives, the experts who participated in the FTA were not the ones who carried out the PHA. The level of abstraction at which the PHA ex-

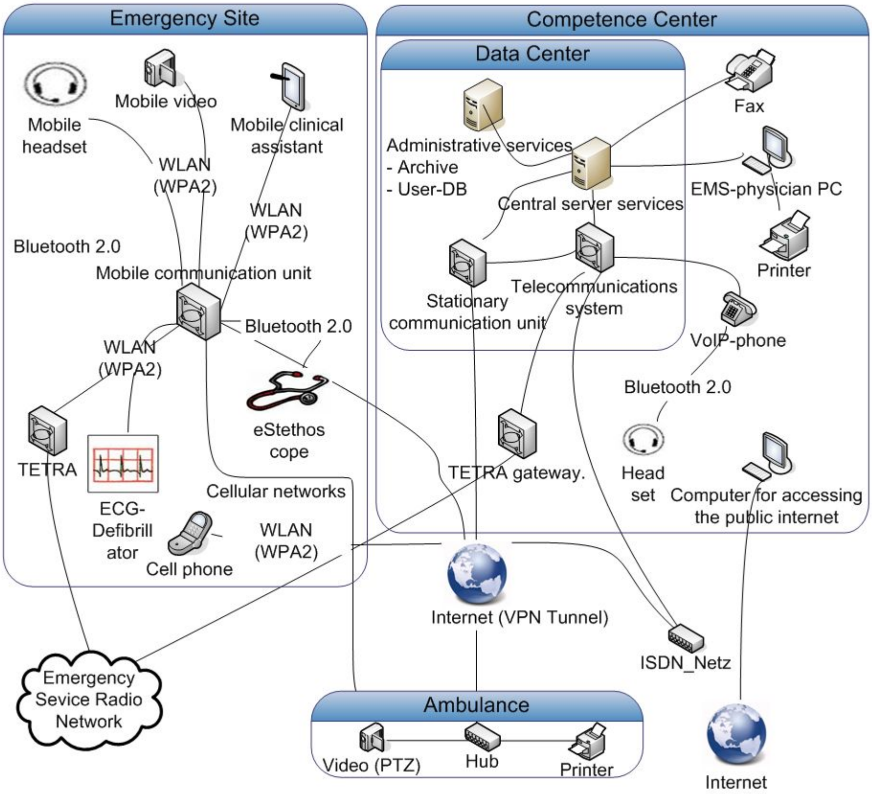

Fig. 2 Structure of the Med-on-@ix system

Table 3 Excert from Preliminary Hazard Analysis

Hazard	Causes	S	W	Prio	Reduction Measure
Mobile Headset					
Reduced basis for diagnosis	Failure of communication via headset	1	c	4	Reserve headsets on the vehicle, cellular phone
Unauthorized interference with data transmission	Lack of encryption	1	d	7	Use of cryptographic techniques
Distortion of diagnosis / treatment	Distortion of communication	2	c	8	Software algorithms for data integrity, Bluetooth 1.0 devices hardly any disturbance
Distortion of communication	Noise	2	c	8	Integration testing, field tests
No energy	Battery Empty	2	c	8	Reserve headsets on vehicle
Battery is not charging	Charger does not work	2	d	12	Control LED for loader, spare battery on vehicle

amined the system proved too coarse for the FTA. Therefore components were split into their separate functions e.g. when examining telecommunications. The ETA was used for a more detailed analysis of 3G coverage based on the FTA. Although important data such as how network coverage translates into available bandwidth and how much of this bandwidth is really needed were not available, the ETA allowed anticipating loss of system functionality in areas with little coverage. In 96 % of the area coverage was sufficient for the live transmission of vital signs and in 70 % of the area it was enough for live video.

5 Conclusion

A methodology for the reduction of hardware risks of TRAS was proposed and successfully applied to the Med-on-@ix system. While categorizing the methods, the work of Biegert was found to be consistent with DIN 60300-3-1 [Com03] and other relevant norms. In the application example PHA, FTA and ETA successfully identified risks qualitatively. Quantifiable data will become available during the test phase and remaining risks will be assessed quantitatively. Further research includes the estimation of the workload needed to carry out each method and the identification of software support for the different methods. Also the methodology to reduce hardware risks should be incorporated into a general methodology reducing other major sources of technical risk in TRAS as well such as software and IT security.

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Open Innovation als Zukunftsstrategie für kleine und mittelständische Unternehmen

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Zusammenfassung Große Unternehmen wie IBM und Lego gelten als erfolgreiche Vorreiter in der aktiven Einbindung von Kunden und externen Ressourcen in die Wertschöpfung des Unternehmens. Open Innovation wird als Erfolgsstrategie der Zukunft gefeiert und von der sich verändernden Unternehmensumwelt gefordert. Doch ist längst nicht klar, welche Chancen und Risiken sich daraus für kleine und mittelständische Unternehmen (KMU) ergeben. Eine Betrachtung der Dimensionen Mensch, Organisation und Technik (MOT) zeigt deutlich, dass enorme Veränderungen auf den Ebenen Technik und Mensch stattgefunden haben und noch stattfinden werden, die KMU zu einer Organisations- und Strategieanpassung zwingen. Daher ist es das Ziel dieses Beitrags, typische Merkmale von KMU systematisch nach den MOT-Ebenen untergliedert aufzuzeigen und erste Hinweise zu geben, wo die Chancen und Risiken dieser Entwicklung liegen können.

Schlüsselwörter: Open Innovation, KMU, MOT-Ansatz

1 Wer macht eigentlich Open Innovation?

Häufig wird gemutmaßt, dass Open Innovation – das derzeitige Schlagwort im Kontext von moderner Innovationsfähigkeit und neuen Unternehmensstrategien – im Wesentlichen eine Strategie für die großen Konzerne sei. Oder Open Innovation wird mit nutzergenerierten Inhalten à la Wikipedia gleichgesetzt und die Anwendungsmöglichkeiten ausschließlich im Internet gesehen (wie bei Flickr, YouTube, MySpace, Facebook und Co.). Tabscott & Williams (2006) [TW06] zeigen hingegen eine große Bandbreite von Entwicklungen auf, die mit dem Phänomen Open Innovation zusammenhängen. Sie reichen von Open Source Initiativen über die Be-

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teiligung von Nutzern an Produktentwicklungen bis hin zu kooperierenden Unternehmensnetzwerken mit offen gelegten Standards.

IBM beispielsweise geht mit großen Schritten voraus: Bereits vor Jahren hat IBM die Entwicklung eines eigenen Serverbetriebssystems eingestellt und begonnen, jährlich Millionen Dollar in die Weiterentwicklung des freien Open Source Betriebssystems Linux zu investieren [TW06]. Dabei handelt es sich um eine Software, für die IBM nicht die Rechte besitzt und die jedem Mitbewerber zu Verfügung steht. IBM hat erkannt, dass in der heutigen Zeit eine eigene Serversoftware kein Alleinstellungsmerkmal mehr darstellt und eine Beteiligung an einer weltweiten Entwicklergemeinschaft effizienter ist. Darüber hinaus versucht IBM die besten Programmierer weltweit über jährliche Wettbewerbe und große Events zu entdecken und für sich zu gewinnen.

Lego war zunächst überrascht, als Ende der 90er Jahre ihre erste Generation der programmierbaren Mindstorms Roboter häufiger von Erwachsenen als von Kindern genutzt wurden, der Quellcode des Betriebssystems innerhalb weniger Wochen geknackt war und im Internet veröffentlich wurde. Statt sich mit Unterlassungsklagen und vermehrter technischer Absicherung gegen die Entwicklung zu wehren, hat Lego die aktiven Mindstorms-User als Innovationsquelle gesehen. Schließlich übertrafen die von diesen Nutzern umgesetzten Funktionen das von Lego beabsichtigte Potenzial um Längen. Für die nächste Generation der Roboter wurden die kreativsten und besten Nutzer aktiv ins Entwicklungsteam integriert [Wil07].

Weitere große Namen wie BMW oder Novartis werden häufig für ihre modernen und offenen Innovationsansätze gelobt. Doch im Zusammenhang mit Open Innovation stellen sich die folgenden Fragen: Haben KMU mit einem viel kleineren Nutzerkreis und weniger öffentlicher Aufmerksamkeit die gleichen Chancen? Gibt es für Nischenprodukte oder Einzelteile von Zulieferern auch sog. Lead-User[1] und wie können diese identifiziert werden?

Ein Blick in die Praxis lässt erkennen, dass auch bei KMU beachtenswerte Erfolgsbeispiele für die aktive Einbeziehung von Nutzern oder Partnern in den Wertschöpfungsprozess existieren:

Die Firma Threadless vertreibt T-Shirts und hat dabei fast alle wertschöpfenden und risikobehafteten Tätigkeiten an die Kunden ausgelagert. Über ein Webinterface gestalten die Kunden die T-Shirts selbst, verbessern und bewerten sich gegenseitig. Threadless stellt seinen Usern die Infrastruktur zur Verfügung und übernimmt die tatsächliche Herstellung. „Die Kunden übernehmen die Werbung, stellen die Models und Photographen für die Katalogphotos und werben neue Kunden“ [RP08]. In Deutschland verfolgt die Firma Spreadshirt das gleiche Geschäftsmodell erfolgreich.

Der Automobilzulieferer Webasto stellt Dachsysteme, Standheizungen und Klimaanlagen her und hat damit traditionell wenig Kontakt zu den Endkunden (den Autofahrern). Viel bedeutender ist hingegen der Kontakt zu den Automobilkonzernen. In Zeiten zunehmenden Marktdrucks ging Webasto aktiv auf die Endkunden

[1] Als Lead-User werden solche Kunden und Nutzer bezeichnet, die Grenzen existierender Produkte ausloten, diese weiterentwickeln und so häufig eigene Prototypen kreieren [TW06].

zu. Das Unternehmen identifizierte Lead-User aus den eingehenden Kundenanfragen und lud diese zu „Innovationswochenenden“ ein. Pro Wochenende konnten im Rahmen von Workshops mehr als 100 neue Ideen entwickelt werden [LD10], von denen Webasto heute profitiert.

Darüber hinaus betreiben viele KMU längst unbewusst Open Innovation. Die Beteiligung von KMU in öffentlich geförderten Forschungsprojekten, wie beispielsweise die der Arbeitsgemeinschaft industrieller Forschungsvereinigungen (AiF), stellt eine aktive Einbeziehung von Forschern in die Innovationsprozesse von KMU dar. Davon können die Unternehmen profitieren, müssen sich für die Teilnahme an den Projekten aber immer ein Stück weit öffnen und auch die wissenschaftliche Veröffentlichung von Projektergebnisse zulassen. Doch die Erfahrung zeigt, dass diese Form der Wissensoffenlegung vor allem Vorteile für die Unternehmen mit sich bringt. Genauso ist die seit Jahren forcierte Bildung von Clustern seitens Industrie und Politik wie auch der Wissenschaft nichts anderes als eine Aktivität auf dem Weg zu gemeinsamen, kooperativen Innovationsprozessen mehrerer Unternehmen.

Open Innovation ist demzufolge gar nicht neu. Piller merkt an, dass „ein Grossteil der funktionalen Neuheiten auf Entwicklungen fortschrittlicher Nutzer zurückgeht. Dies gilt bereits seit den Anfängen der Industrialisierung [...]“ [Pil07]. Es stellt sich also die spannende Frage, was genau neu ist und ob wirklich die Notwendigkeit neuer Strategien auf nahezu alle Firmen, insbesondere KMU zukommt. Oder geht es einfach nur um „eine moderne Version des Vorschlagwesens“ [Wil07], die durch ein paar neue Internettechnologien unterstützt wird? Zur Beantwortung dieser Fragen muss systematisch analysiert werden, wo die tatsächlichen Neuerungen liegen und wie diese mit den typischen Merkmalen von KMU zusammenhängen. Einen ersten Näherungsschritt bietet daher der folgende Abschnitt dieses Beitrags, welcher sich mit der systematischen Betrachtung der drei Dimensionen Mensch, Organisation und Technik beschäftigt.

2 Open Innovation unter Berücksichtigung der Ebenen Mensch, Organisation und Technik

Das Thema Innovation wird mittlerweile ganzheitlich unter Einbezug der drei wichtigen Ebenen Mensch, Organisation und Technik betrachtet. Bei Open Innovation hingegen liegt der Fokus der derzeitigen Diskussion noch auf der Technik während der Mensch als bedeutender Akteur sowie die hinter dem Innovationsprozess stehende Organisation häufig nur am Rande betrachtet werden. Dabei ist für KMU, insbesondere für die Öffnung ihrer Innovationsprozesse, die ganzheitliche Betrachtung von Mensch, Organisation und Technik von besonderer Bedeutung.

Die Veränderungen der jüngeren Vergangenheit im Bereich der Technik liegen auf der Hand und haben die Diskussion um Open Innovation maßgeblich geprägt [RP08, How06, Hip05]. So haben die kontinuierliche Optimierung von Computern sowie die Öffnung des Internets für den privaten Gebrauch (wichtig sind hierbei auch die Zurverfügungstellung von Breitbandanschlüssen und die Einführung von

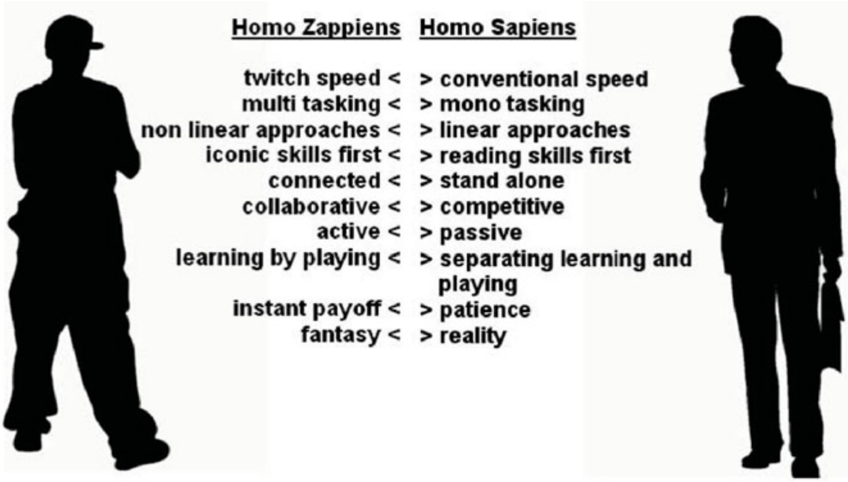

Abb. 1 Homo Zappiens vs. Homo Sapiens [VV06]

kostengünstigen Flatrates) zu einer vernetzten digitalen Welt geführt, die von der neuen Generation akzeptiert und genutzt wird. Web 2.0 Technologien wie Wikis, Blogs, Tagging oder Content-Management-Systeme haben maßgeblich dazu beigetragen, Nutzer an der Entstehung und Weiterentwicklung von Software- und Internetangeboten zu beteiligen.

Kunden oder Nutzer treten folglich nicht mehr nur als Konsumenten auf, sondern gleichzeitig als Produzenten, wofür Toffler bereits Ende der achtziger Jahre den Begriff des Prosumers geprägt hat [Tof87]. Bekanntestes Beispiel hierfür ist Wikipedia. Die Nutzer dieser Onlineenzyklopädie können sowohl Wissen konsumieren als auch schaffen, indem sie selbst einen Eintrag verfassen uns somit ihr Wissen für andere zur Verfügung stellen. Bei genauer Betrachtung lassen sich noch weitere aktuelle Veränderungen in der Dimension Mensch ausmachen. Schon in jungen Jahren ist es für die Menschen heutzutage selbstverständlich, sich in virtuellen Welten zu bewegen und sich schnell auf Neuerungen im Bereich der Technik einzulassen. Diese „neue" Generation zeichnet sich dadurch aus, dass sie auf digitalem Wege ständig miteinander vernetzt ist und kommuniziert. Des Weiteren spielen Fantasie und spielerisches Lernen eine wichtige Rolle. Wichtigste Eigenschaft im Zusammenhang mit Open Innovation ist jedoch der Drang, sich aktiv an allem, was um sie herum geschieht, zu beteiligen und dies auch umzusetzen sowie das erlangte Wissen zu teilen. Veen [VV06] bezeichnet diese heranwachsende und nun erstmals den Arbeitsmarkt erreichende Generation als „Homo Zappiens" und konstatiert ihre grundlegend anderen Denk-, Lern- und Verhaltensmuster. Abbildung 1 stellt diese den Eigenschaften des „alten" Homo Sapiens gegenüber.

Bei der Betrachtung der Ebene Mensch wird so schnell deutlich, dass hier ein Wandel stattgefunden hat und weiterhin stattfindet, auf den sich die Unternehmen, insbesondere bei der Öffnung ihrer Innovationsprozesse, einlassen sollten, um Open

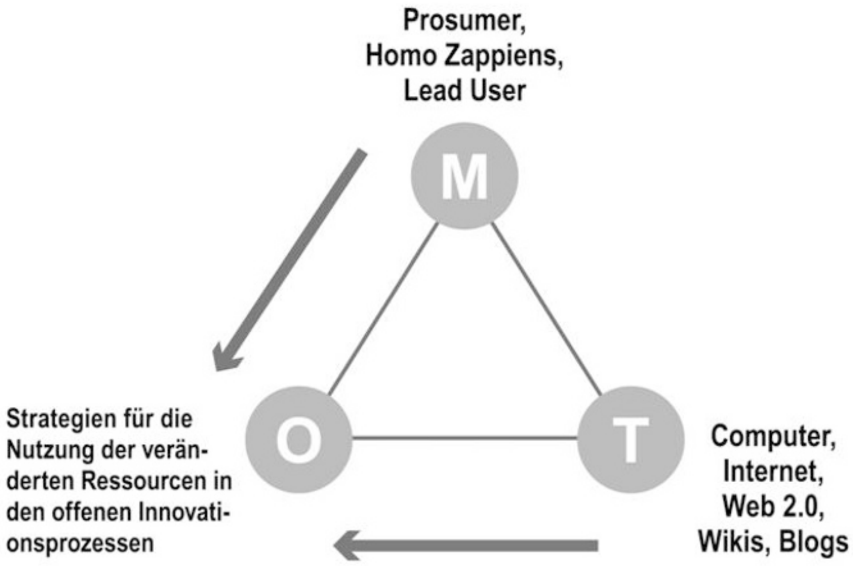

Abb. 2 Aktuelle Trends in den Dimensionen Mensch, Organisation und Technik

Innovation für sich erfolgreich einsetzen zu können. Bei der näheren Betrachtung dieser Gegebenheiten kommt die Frage auf, ob mit der neuen Generation von Mitarbeitern „Closed Innovation" nicht sogar so gut wie unmöglich wird, da diese Art des Innovationsmanagements den grundlegenden Herangehensweisen der neuen Generationen wie etwa dem „Homo Zappiens" widerspricht.

Auf den ebenen Mensch und Technik stehen den Unternehmen folglich nicht nur die externen Ressourcen zur Verfügung, um Open Innovation einsetzen zu können sondern die bereits erfolgten Veränderungen erzeugen Druck, die Ebene Organisation den neuen Gegebenheiten anzupassen (vgl. Abb. 2).

Hier sei noch einmal betont, dass für ein erfolgreiches offenes Innovationsmanagement alle drei Ebenen von großer Bedeutung sind. Mensch, Organisation und Technik unterliegen aus unternehmenskybernetischer Sicht einer gegenseitigen Abhängigkeit. Wenn in einer der drei Ebenen eine Veränderung oder ein Soll-Ist-Ungleichgewicht vorliegt, hat dies Einfluss auf die beiden übrigen Ebenen. Die Veränderung eines der Elemente bewirkt in der Regel keine grundlegende Entwicklung der Innovationsfähigkeit. Das Zusammenspiel der drei Ebenen sowie die Rückführungen untereinander sind der Schlüssel zu einer erfolgreichen Innovationsstrategie.

Zurzeit fehlen den Unternehmen, insbesondere den KMU, Strategien zur Vorbereitung ihrer Mitarbeiter auf offene Innovationsprozesse sowie für deren Umsetzung. Ein Grund hierfür ist die Ressourcenknappheit der KMU. So fehlt es beispielsweise an Kapital und Arbeitskräften, um sich näher mit Open Innovation zu beschäftigen und eine geeignete Strategie zu entwickeln bzw. die Unternehmensorganisation anzupassen [Mey06, Mug98, PPS00, LVvK]. Ein weiterer Grund kann sein, dass die Veränderung, die mit einer neuen Generation Mensch, dem Homo Zappiens[2], den Unternehmen bevorsteht, von der „Führungskräften der alten Generation“ noch nicht wahrgenommen wird.

Dabei ist zu bedenken, dass es gerade für KMU zukünftig zwingend notwendig sein wird, den Open Innovation-Gedanken aufzunehmen und zu vertiefen, um gegenüber anderen Unternehmen wettbewerbsfähig zu bleiben. Der folgende Abschnitt zeigt daher die speziellen Merkmale von KMU auf und leitet daraus erste Ideen für die Einordnung dieser in ihre Stärken, Schwächen, Chancen und Risiken in Bezug auf die Öffnung des Innovationsprozesses ab.

3 Merkmale kleiner und mittelständischer Unternehmen

Angesichts des Gedankens, dass die Verwendung von Open Innovation immer unumgänglicher wird, aber auch nicht zwingend neu für KMU ist, bedarf es einer genauen Betrachtung der Merkmale von KMU. Es können Erkenntnisse erlangt werden, ob z. B. Organisationsstrukturen kompatibel mit der Strategie sind und ob es Möglichkeiten gibt Open Innovation effizient zu nutzen. Um die Potenziale zur Öffnung des Innovationsprozesses zu identifizieren, werden zunächst die wesentlichen Eigenschaften, die ein KMU von einem Großunternehmen abgrenzen, erhoben.

Zunächst können zur Abgrenzung verschiedene Definitionen anhand quantitativer Maßstäbe herangezogen werden (vgl. HGB; Europäische Kommission, IfM Bonn, etc.). Laut Europäischer Kommission setzt sich die Größenklasse der KMU aus Unternehmen zusammen „[. . .] die weniger als 250 Personen beschäftigen und die entweder einen Jahresumsatz von höchstens 50 Mio. EUR erzielen oder deren Jahresbilanzsumme sich auf höchsten 43 Mio. EUR beläuft.“ [Kom06]

Mittels quantitativer Kriterien kann eine erste Orientierung zur Differenzierung zwischen KMU und Großunternehmen stattfinden. Die Messung ökonomischer Zahlengrößen ist zwar relativ genau durchführbar, lässt jedoch keinen Einblick in das Wesen und die Eigenschaften von KMU zu. Durch die Identifikation von qualitativen Merkmalen können die charakteristischen Faktoren unter Annahme des M-O-T-Gedankens deutlicher dargestellt werden. Denn gerade die organisatorischen und sozialen Faktoren spielen die entscheidende Rolle für die Ermittlung der Potenziale zur Durchführung von Open Innovation. Die in der Literatur, unter anderem von Pichler/Pleitner/Schmidt (2000) [PPS00], Pfohl (2006) [Pfo06], Mugler (1998; 2008) [Mug98, Mug08], IfM Bonn (2010), Gelshorn/Michallik/Staehle (1991) [GMS91], Siemers (1997) [Sie97], Lindermann et al. (2009) [LVA$^+$] häufig dargelegten qualitativen Merkmale[3] werden im Folgenden dargestellt (Tab. 1).[4]

[2] An anderen Stellen auch unter den Stichworten Generation N oder Netgeneration angesprochen.

[3] Ausgegrenzt werden jene Faktoren, die keinen Bezug auf das Innovationsmanagement haben.

[4] Es muss beachtet werden, dass die aufgeführten Faktoren nicht für alle KMU zutreffen, da z. B. die Unterscheidung nach Branche und Standort nicht einbezogen wird. Des Weiteren können einige Merkmale als Kontingenzfaktoren identifiziert werden.

Tabelle 1 Merkmale von KMU

MENSCH	
Unternehmer	
	In der Person des Unternehmers ist zugleich die Funktion des Eigentümers und Leiters des Unternehmens vereint (Einheit von Eigentum, Leitung, Entscheidung, Risiko und Kontrolle); Unternehmenskultur wird von Unternehmer bestimmt; Innovationsbereitschaft hängt von der Persönlichkeit des Unternehmers ab; Hingabe an Unternehmen; starke emotionale Bindung; patriarchalische Führung; geringe Bedeutung strategischer Planung; mangelnde betriebswirtschaftliche Kenntnis
Mitarbeiter	
	Mangel an Personal; wenig funktionsspezifische Mitarbeiter hinsichtlich betriebswirtschaftlicher Aufgaben; Fachwissen liegt in einem Bereich; Mitarbeiterzufriedenheit; hohe Motivation; Flexibilität der Mitarbeiter; Netz von persönlichen Kontakten zu Kunden, Lieferanten und relevanter Öffentlichkeit
ORGANISATION	
	Hohe Flexibilität bezüglich der Unternehmensorganisation; traditionelle Organisationsformen (Linienorganisation); kaum Aufgabendelegation; geringer Formalisierungsgrad; flache Hierarchie; geringe Arbeitsteilung; enger und informeller Kontakt zwischen der Unternehmensleitung und den Mitarbeitern; kurze und überschaubare Informationswege; hohe Partizipation und wechselseitige Abstimmung der Mitarbeiter (Sozialcharakter des Unternehmens)
TECHNIK	
	Knappe Ressourcenausstattung; keine dauerhafte institutionalisierte F&E- Abteilung; intuitiv ausgerichtete F&E; wenig Verwendung von Web 2.0; beschränkter Einsatz von Informations- und Kommunikationstechnologie (IKT)
SONSTIGE	
Leistung	
	Individuelle, differenzierte Erbringung; keine Ausnutzung von „economies of scale“ (keine Massenproduktion)
Situation	
	Zeitmangel; schwieriger Zugang zu Kapital; meist nur regionale Tätigkeit; Abhängigkeit von größeren Firmen, die meist als Abnehmer fungieren; schwieriger Schutz von „intellectual property“; geringer Markteinfluss; Unternehmen wird stark von unsicheren externen Einflüssen tangiert;
Innovation	
	Überproportionale Belastung durch Fixkosten der Innovationen; relativ kurzer Zeitraum zwischen Erfindung und wirtschaftlicher Nutzung; geringe Diversifikation des Risikos; interne Innovationsfinanzierung

Bevor einige Merkmale herausgegriffen und im Hinblick auf das (offene) Innovationsmanagement näher betrachtet werden, sei betont, dass es sich bei den in der Tabelle aufgelisteten Merkmalen um Extremformulierungen handelt, die in der Realität selten so vollständig in einem KMU zusammenkommen.

Die individuelle, differenzierte Leistungserbringung sowie der enge persönliche Kontakt zu den Kunden geben bereits erste Hinweise, dass Open Innovation in einigen KMU (häufig unbewusst) vollzogen wird. Der Mangel an Ressourcen, insbesondere an Kapital, zwingt die Unternehmen in vielen Fällen zur Kooperation mit externen Wissensträgern. Da in KMU vorherrschend kurzfristig-intuitiv angelegte F&E Abteilungen vorhanden sind, prädestiniert dies KMU für die Integration eines offenen und kooperativen Innovationsprozesses [GE05]. Die Nutzung von externen Wissenspotenzialen, in Form von Technologie- und Wissenstransfer bedeutet für KMU eine Möglichkeit, dem Nachteil der knappen Ressourcen bezüglich Personal und Kapital entgegenzuwirken [Mey06, Mug98, PPS00, LVvK]. Das Wissen kann nicht nur zur Identifikation von Bedürfnis- und Lösungsinformationen und zur Erweiterung der eigenen F&E genutzt werden, sondern auch um die marktbezogenen und technologischen Unsicherheiten zu erkennen. Jedoch steht dem gegenüber, dass Techniken des Wissenserwerbs, wie Informations- und Kommunikationstechnologien häufig lediglich zur Unterstützung des Tagesgeschäfts genutzt werden [LVA+].

Dem Menschen innerhalb des Unternehmens wird eine besondere Bedeutung beigemessen. Die zentrale Stellung des Unternehmers kann sich sowohl positiv als auch negativ auf das Potenzial von Open Innovation in KMU auswirken. Auf der einen Seite zeichnet sich die Einheit von Eigentum, Entscheidung, Leitung und Kontrolle bei gleichzeitigen kurzen Informationswegen, durch eine schnelle Reaktionsfähigkeit bezüglich Umweltveränderungen und einer potenziellen Flexibilität in der Unternehmensorganisation aus [Das94]. Auf der anderen Seite wirkt sich die alleinige Entscheidungsbefugnis bei fehlerhaften Beschlüssen, beispielsweise bezüglich einer Abwehrhaltung gegen externes Wissen (NIH-Syndrom) oder falscher Innovationausrichtung, auf den gesamten Erfolg des Unternehmens aus [Mey06]. Weiterhin steht die mit der Nutzung von Web 2.0 verbundene Selbstorganisation im Widerspruch zu dem vorherrschenden patriarchalem Führungsstil des Unternehmers und der daraus folgenden mangelnden Partizipation der Mitarbeiter [LVA+].

Die Implementierung einer Open Innovation-Strategie bedeutet gerade für traditionell geführte Unternehmen einen erheblichen Wandel. So muss der Unternehmer, welcher womöglich Jahre erfolgreich mit einer internen Produktentwicklung war, bereit sein, das externe Wissen anzunehmen. Er muss sich dem Wandel des Menschen außerhalb seiner Unternehmensgrenzen bewusst werden, sowie den Glauben ablegen, dass neue Technologien, wie Web 2.0 keinen zukünftigen Einfluss auf ihr Unternehmen haben werden [LVA+]. Weiterhin sollte der Unternehmer einen gewissen Mut zum Risiko haben, um eine Open Innovation-Strategie zu implementieren. Nicht nur aufgrund der mangelnden Risikodiversifikation, sondern auch aufgrund des schwierigen Schutzes von „interlectual property", kann sich Angst vor der Öffnung des Innovationsprozesses beim Unternehmer verbreiten [RD91, GW10]. Dennoch muss dieses Risiko gegenüber dem Risiko der Diskontinuitäten in Technologie und Bedürfnissen und dem daraus folgenden Versäumnis abgewogen werden. Voraussetzung hierfür ist, dass KMU explizit definieren müssen, wo sie sich öffnen können und wo es weiterhin gilt, Wissen zu bewahren, um Erleinstellungsmerkmale zu erhalten.

Ein weiterer Faktor auf der menschlichen Ebene ist das Wissenspotenzial. Der zentrale Unternehmer gründet oder agiert mit seinem Unternehmen häufig in dem Fachgebiet, in welchem er seine Ausbildung genossen hat. Auch das Wissen der

Mitarbeiter liegt vorwiegend in einem speziellen Bereich. Dies impliziert, dass in KMU meist ein ausreichendes Potenzial an Wissen zur Erfindung neuer Technologien vorliegt. Doch mangelt es KMU aufgrund der starken Technikorientierung an Kapazitäten in Bezug auf Herstellungsverfahren, Marketing und Strategie, um eine Innovation effizient in den Markt einzuführen [LPYP10, Not94]. Dies wirft einen neuen Aspekt der Open Innovation-Strategie auf. KMU haben scheinbar das Potenzial im F&E Bereich und arbeiten auch in vielen Fällen bereits mit Kunden zusammen, jedoch fehlt es an einer Zusammenarbeit in der Kommerzialisierungsphase [LPYP10].

Der Organisation wird bei Innovationsprojekten ebenfalls eine besondere Aufmerksamkeit gewidmet, da sie eine entscheidende Kraft für die Innovationstätigkeit von Unternehmen repräsentiert [Sie97]. Aufgrund der offenen und persönlichen Kommunikation innerhalb der KMU kann der Aufwand des Abstimmungsbedarfes zwischen den verschiedenen Bereichen des Unternehmens reduziert und effizienter gestaltet werden [Mug98]. Durch die Flexibilität der Organisation können die durch die Implementierung einer Open Innovation-Strategie hervorgerufenen strukturellen Veränderungen des Unternehmens mit geringen Kosten bewältigt werden. Im Hinblick auf die Verwendung und Integration von externem Wissen wird ein gut organisierter Innovationsprozess meist unumgänglich [VdVdJVdR09]. „Mit dem Einsatz von Web 2.0 stehen Unternehmen vor einem fundamentalen Wandel in Richtung selbstorganisatorischer und partizipativer Strukturen“ [LVA$^+$]. Faktoren, wie der Mangel an Zeit, verlangen, dass bei der Suche mit modernen Kommunikationsmitteln eine strukturierte Vorgehensweise angewandt wird. Es muss eine Balance zwischen Innovation und täglichen Aufgaben gefunden werden [VdVdJVdR09]. So impliziert dies auch wiederum einen Wandel auf der menschlichen Ebene. Mitarbeiter müssen in Richtung der neuen Informationssuche ausgebildet werden. Es sind zunehmend neue Rollen mit speziellen Aufgabenbereichen für Open Innovation zu vergeben. Eine Kernaufgabe für die Mitarbeiter liegt darin, die Kooperationspartner zu erkennen, effizient das Angebot externen Wissens zu nutzen und wichtiges Wissen von belanglosem zu separieren [GW10]. Demzufolge steht dem Mangel an Personal und Zeit die Anforderung, neue Aufgaben neben den operativen Tätigkeiten zu bewältigen, gegenüber.

4 Zusammenfassung und Ausblick

Beispiele wie Threadless und Webasto zeigen, dass bereits einige KMU durch die Implementierung einer Open Innovation-Strategie einen erheblichen Wettbewerbsvorteil erlangen. Um eine Open Innovation-Strategie einzuführen, müssen sich KMU über den Wandel innerhalb der Dimensionen Mensch, Organisation und Technik bewusst werden und ihre Potenziale identifizieren, erfolgreich auf den Wandel reagieren zu können. Der M-O-T Ansatz verdeutlicht, dass den Entwicklungen in den Dimensionen Mensch und Technik und dem Zusammenspiel der drei Faktoren eine hohe Aufmerksamkeit gewidmet werden muss. Es ist unumgänglich, dass moderne Technik neue Möglichkeiten der Zusammenarbeit über Unternehmensgrenzen hinweg ermöglicht und dass eine Generation auf den Arbeitsmarkt drängt, die in Bezug auf Kommunikation, Kooperation und Informationsverarbeitung neue Wege beschreitet.

Die Merkmale von KMU geben insbesondere Hinweise auf interne Stärken und Schwächen zur erfolgreichen Durchführung einer Open Innovation-Strategie. Die wichtigsten sind hier noch einmal zusammengefasst: Die Separierung von wichtigem und unwichtigem Wissen sowie zu teilendem und zu „versteckendem" Wissen muss als Aufgabe erkannt und in der Unternehmensstruktur als neue Kernaufgabe abgebildet werden. In der Umsetzung von Innovationen sind KMU aufgrund ihrer spezifischen Struktur und Kultur häufig schneller und kostengünstiger. KMU sollten ihre Netzwerke (Kunden und wissenschaftliche Partner) in der Kommerzialisierungsphase besser nutzen.

Daher wird das Institut für Unternehmenskybernetik in Zusammenarbeit mit dem Lehrstuhl für Technologie- und Innovationsmanagement der RWTH Aachen University im Rahmen des AiF-Forschungsprojekts „Invoice" auf Basis der zuvor aufgeführten Merkmale eine SWOT-Analyse durchführen, welche die Unternehmenssituation in Bezug auf Open Innovation auf anschauliche Weise darlegt. Mittels der SWOT-Analyse können die potenziellen Treiber einer Open Innovation-Strategie erfasst und die zuvor angeschnittenen potenziellen Chancen und Risiken weiter ausgeführt werden.

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Strategic Implementation of Open Innovation Methods in Small and Medium-Sized Enterprises

Sabine Schwab, Jessica Koch, Paul Flachskampf, Ingrid Isenhardt

Abstract Over the last decades, an increased appreciation of external contributors within the product development process can be noticed as a significant development within innovation management. This open form of innovation is summarised under the concept of Open Innovation. Yet, it is difficult to apply it to small and medium-sized enterprises (SME) as they struggle to implement these Open Innovation methods. It is therefore very important to develop appropriate organisational forms for these enterprises. In this context, the article describes both the environmental changes and the specific characteristics of SME as well as their impact when using Open Innovation in SMEs. The goal of this article is to develop a first concept for the implementation of Open Innovation methods into the innovation management of SME.

Key words: Open Innovation, H-O-T Approach, SME, Conceptual Framework

1 Introduction

The successful generation of innovation is one of a company's constant challenges, especially for the numerous technology-oriented SMEs in Germany [Sch05]. The reason is the rapid technical change and the shortened development periods of technical products. Enterprises must keep up with these changes. Otherwise they will not be able to create effective and efficient innovations and – with regard to this – be competitive, because strong innovation ability is the key for a company's success and the increase of the company's value [Sch05]. Furthermore, due to a lack of information and knowledge concerning the appropriate methods, many enterprises cannot bring their new product developments to the market [Fra07]. Over the last

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years, the increased appreciation of externals as contributors (customers, suppliers, researchers, and universities) to the innovation process has been a significant development within innovation management [Che03]. Due to the businesses' objective of generating innovations the development process is opened up to external contributors. These will be involved from generating the idea across developing a concept and the product, testing the product and the prototype to launching the final product [Che03].

Large enterprises with adequate resources, especially staff and other assets, can already flexibly organise their innovation management, adapting it to their dynamic environment and using Open Innovation. The question is whether SMEs with fewer resources and smaller user groups (often due to offering niche products) can adapt their organisation and adopt Open Innovation successfully.

Therefore, the Institute for Management Cybernetics e.V. (IfU) and the Technology and Innovation Management Group (TIM) at RWTH Aachen University work together on the research project "Invoice – Efficiency of Open Innovation for Small and Medium-sized Enterprises", promoted by the Consortium of Industrial Research Associations (Arbeitsgemeinschaft industrieller Forschungsvereinigungen, AiF). Within this project, the institutes develop a tool to control Open Innovation strategies in SME.

This paper focuses on one part of the mentioned tool, more precisely the process of selecting the adequate Open Innovation method(s). The structure is as follows: Sect. 2 describes the state of the art concerning the three aspects human, organisation and technology (the so called H-O-T approach), Open Innovation and its methods. Section 3 deals with a first conceptual framework for the implementation of Open Innovation methods supported by the mentioned H-O-T approach. The final section will give the conclusion and future prospects.

2 State of the Art

2.1 The H-O-T Approach

To clarify the importance of system-oriented thinking and acting as well as adapting the organisation to the changes with regard to the human and technology aspects, the so called H-O-T approach will be introduced.

The H-O-T approach emphasises the interdependency among the basic aspects of an enterprise: the humans, the organisation, in which they operate, and the technology which surrounds them. New production systems or rather functions promise success if they are meant to optimise the implementation of technology. This also includes the design of the organisation and the qualification of the employees which shows the importance of optimisation.

First of all, the human aspect has to be considered due to its influence on the organisational and technology aspects as well as its ability to control both. Within the relationship between humans and technology, it is very important that technology is not regarded as a practical constraint but as a creative assignment. On this note, technology is meant to be a function as a tool for the human action [Har05]. The machine, for example, is considered as the extended arm of the human. In addition, the machine should be regarded as such in order to improve human abilities and competences.

The connection between the human and organisational aspects is characterised by two types of living systems. The alternating structurally interconnected development processes are the centre point of these two. Within the H-O-T approach, the organisation is understood as a living social system. Social systems consist of the individuals' communication which corresponds to their acting. Therefore, people are a very important factor for the success of the implementation of a new system. By means of the way they react to changes, they can encourage or deny changes [MTM08].

2.2 Open Innovation

For the purpose of this paper, Open Innovation is defined as "the formal discipline and practice of leveraging the discoveries of others as input for the innovation process through formal and informal relationships [RP09]". It is in contrast to a classical closed process in which enterprises only use ideas and technical competences which are available in their own domain. In addition, they only use competences of well-known partners who are integrated in their network [Che03].

The objective of Open Innovation is to receive information about need and the respective solution involving external users. Von Hippel describes need information as the way customers or other problem solvers show the enterprise which kind of product or service should be generated [Hip94]. The information, which shows the enterprises how to create new products or services, – also provided by the problem solvers – is called solution information [Hip94]. By implementing external knowledge, the enterprise employs a wider field to identify ideas and solutions [Pil03].

The main idea of Open Innovation is to collect needed information through active integration of customers and users into all phases of the innovation process, instead of the classic measurement of market research or trend scouting. In this context, needed information is the information about customer needs and market demands. Through the use of a network of external experts, the search for a solution is supposed to be optimised. Solution information forms the basis for activities of product engineers in the innovation process. This consolidation does not occur in the form of cooperation between research and development, but through an open appeal to an undefined network of contributors. Thus, they assist in the development of assignments. This effect is well known as interactive adding value or crowd sourcing [RP09, How06, Hip05].

Open Innovation concentrates on the enterprises' abilities in order to avoid market-oriented and technological uncertainties especially at the early stage of the innovation process. However, it is meant to identify and integrate knowledge in this process still outside the entrepreneurial borders. In this context, Open Innovation should increase the effectiveness as well as the efficiency in the innovation process.

2.3 Methods to Implement Open Innovation

Several methods for the implementation of Open Innovation strategies have already been developed. Some of the existing methods will be described briefly in the following paragraphs and used for a first conceptual framework in Sect. 3.

The *Lead-User-Method* is a qualitative procedure. The method aims at the identification and active implementation of selected users in order to generate the innovation of new products and projects [Hip94]. Lead-User-Workshops promote the creative customer and operator potential through utilising peer effects [LHvH05].

Many Open Innovation approaches are based on *User-Innovation and Co-Design Toolkits* [FP04]. On the one hand, these Toolkits are production configurations which determine a customer tailored production specification in order to receive a high variant diversity (mass customisation). On the other hand, the Innovation-Toolkit's objective is to enable current and potential customers to bring new and creative products or product variants about. First of all, the objective of the Toolkit's implementation is to provide a tool to the user which helps to create own ideas and solutions. Yet, the main focus of this tool is to identify the users' needs.

Communities of Open Innovation argue that innovation is mostly the result of the cooperation among several contributors. They work to achieve the goal set as well as the creation of new ideas within a virtual community. In terms of a Commons-Based-Peer-Production [Ben06], online communities are particular successful in the field of Open Source software. Also, within the innovation process, existing virtual communities can be observed.

In terms of an *Idea-Competition*, the creativity and quality of the participants' contributions are supposed to be stimulated. In this context, a reward is an additional incentive to participate. The applicability of the Idea-Competition method is quite broad and ranges from a continuous introduction as an open platform to an individual assignment to solve specific technical problems [Ern04].

Another method has its origin in the *Not-invented-here-syndrome* (NIH) that deals with the disregard for already familiar knowledge but from another origin [KA82]. There may have been the chance to transfer solutions for their problem from other sections of the enterprise or from its external environment. But when enterprises are looking for familiar solutions, in most cases, they are looking for research fields in which they already operate. In research, the problem of the solely local search is named as *Local Search Bias* (LSB) [KA02]. Both NIH and LSB can be resolved through Open Innovation.

The identification and integration of external knowledge in the innovation process also provides many opportunities for SMEs. Furthermore, they are an important strategic factor in terms of the high strategic meaning of innovation ability. For example, the reduction of *Time-to-Market* and *Cost-to-Market* are of particular importance [RP09]. The reduction of Time-to-Market means the shortening of the period from the beginning of the development phase to the market launch. The reduction of the Cost-to-Market refers to the product costs from the product development process to the market launch.

In summary, the focus of the investigations for the field of Open Innovation concentrates on conceptual and application areas. Within this research field, the bigger part of the investigation deals with large enterprises; SMEs have not received much attention as of now. Therefore, it is crucial to create an appropriate organisation form for SME which allows on the one hand for the incorporation of Open Innovation methods and on the other hand for the application of these strategies. The arrangement of proper enterprise structures can only be effected through a comprehensive consideration of the three aspects, human, organisation, and technology, which will be explained in the following section.

3 A First Conceptual Framework for the Implementation of Open Innovation Methods in SMEs Based on the H-O-T Approach

The first two sections showed that the Open Innovation methods, introduced by the changes in the technological and human aspects, will become an important way to generate new products and services and to achieve the enterprises' sustainable success also for SMEs.

Based on the H-O-T approach, the mentioned aspects influence one another and also the third one: the organisation. Therefore, this section will discuss how SMEs have to change their organisation, especially concerning their innovation management, and adapt it to the changes in the human and technology aspects. To relate the following aspects to the special conditions of SMEs, their characteristics are compiled and have to be analysed with regard to Open Innovation. It will then be possible to decide, whether organisational structures are compatible with the Open Innovation methods and if there is a chance to use it efficiently. As a first step, the characteristics which separate SMEs from large enterprises, will be identified and discussed.

In order to be able to comprehend the correlation between the characteristics and the three aspects of the H-O-T approach as well as the conceptual framework in Sect. 3.2 some basic information about the changes for each of the three aspects, human, organisation, and technology, is given:

Already at the end of the 1980s, Toffler introduced another term to describe a new generation of humans: the "prosumer" – the cross between customers and producers [Tof87]. The users of the online encyclopaedia *Wikipedia* for example consume and create knowledge. On the one hand they read the articles of other users; on the other hand they create their own articles and share their knowledge. This "new" generation is characterised by digital networking und communication. The "prosumer" need not exist nor does he play a decisive role in every SME. But analysing and discussing this problem is beyond the scope of this paper.

These changes as well as the discussions of Open Innovation were brought forward by many technological innovations (e.g. [RP09]). Some examples are the continuous optimisation of computers and the opening of the internet for personal use. At the same time, technology is characterised by open applications of the Web 2.0, Wikis, Blogs, etc. These innovations have been causing a connected digital world which is accepted and used by the new generation (cf. the mentioned "prosumer").

To achieve their sustainable success, companies must respond to these changes and adapt their organisation to them.

3.1 The Characteristics of SMEs as Opportunities and Threats Concerning the Implementation of Open Innovation Strategies

There are several definitions in terms of quantitative classification [cf. e.g. European Commission]. These quantitative classifications allow for a first differentiation between SMEs and large enterprises. It is possible to take exact measurements of such economic data but the characteristics of an SME do not necessarily become evident. It is required to identify qualitative factors. In a second step, these qualitative factors have to be clarified by using the H-O-T approach. Especially the organisational and social factors are important to identify the SME's potentials concerning Open Innovation. The following paragraphs show and discuss some generally accepted qualitative factors of SME referring to innovation management, which were compiled from several references. All of the listed characteristics in the next subsection are extremes. In the reality, they do not necessarily all exist in parallel in one single SME although every SME combines many of them.

3.1.1 Human

The human is one of the most important elements in SMEs. Especially the central position of the entrepreneur has an effect – both positive and negative – on the implementation and success of Open Innovation. The unity of property, management, decision, risk, and control in conjunction with short information paths allows for fast reactions concerning external changes and also a flexible organisation [Das94]. This aspect shows a first connection between the human and the organisational aspect. Otherwise the entire success of the SME is impaired by potentially wrong decisions by the entrepreneur, for example declining the implementation of external knowledge (Not Invented Here-Syndrome, NIH [KA82]), or by wrong innovation methods [Mey06].

One of the problems concerning the implementation of Open Innovation in SME is the risk aversion of the entrepreneur, especially to the opening of the innovation process. This is caused and tightened by the difficult protection of the SME's "intellectual property" (e.g. [Wid10]). The entrepreneur has to decide, whether it is riskier to share the internal knowledge or to miss adapting to the external changes and requirements.

Both the entrepreneur's and his employees' knowledge is limited to a specific field. In addition to this, there is a lack of staff to develop manufacturing methods and strategies for successful launches [Lee10].

It is necessary to train the employees concerning the new ways to search for information. The implementation of Open Innovation causes new roles with specific requirements. Some of the new main tasks are to identify cooperation partners, use the offered external knowledge efficiently and separate important knowledge from irrelevant [Wid10].

The networking aspect – especially personal contact to the customers – is a very important requirement for the implementation of Open Innovation.

3.1.2 Organisation

Some SMEs are working with their customers already. The missing point is the implementation of external knowledge in the phase of commercialisation [Lee10].

Another important aspect concerning innovation activities in enterprises is project organisation [Sie97]. Because of the informal and personal communication between the management and the employees in SMEs, the coordination of the various departments is organised very efficiently [Mug98]. The organisation in SMEs is characterised by high flexibility. Hence, the structural changes inside the enterprise due to the implementation of Open Innovation could be managed without incurring high costs. One of the most important elements concerning the integration of external knowledge is to manage well-organised innovation processes [dVea09].

Using Web 2.0, enterprises have to create more self-organised and integrated structures [Lin09]. Because of lacking resources and factors like time, the use of modern communication media has to be well-structured. The balance between creating innovations and handling daily tasks is crucial [dVea09]. This is related to the changes to the human aspect.

Particularly, traditionally managed SMEs undergo a revolution by implementing the methods of Open Innovation. Hence the entrepreneur, who was successful by using closed innovation strategies for the last years, must be prepared to implement external knowledge. He must accept and use the changes of the enterprise's environment and the new technologies, e.g. Web 2.0, because they definitely will have an impact on the SME's future [Lin09].

All these aspects point out the connections between the three aspects human, organisation and technology.

3.1.3 Technology

The R&D department – if there is such a department – plans short-term and works intuitively. Thus, this constitutes another good point to integrate an open and co-operative innovation management in SMEs [GE05]. SMEs could use the external knowledge to receive more information about requirements and solutions as well as to expand their R&D activities.

Furthermore, using external knowledge gives SMEs a chance to overcome their handicap of limited resources concerning staff and capital (e.g. [Lin09]).

It is also possible to identify uncertainties concerning markets and technologies. This is accompanied by the fact that methods of acquiring knowledge (e.g. information and communication technologies) often only support the day-to-day business [Lin09].

3.2 A Concept for the Implementation of Open Innovation Methods

The next step is to develop a first concept for the implementation of Open Innovation methods into the innovation management of SMEs. In this process the characteristics mentioned (see Chap. 3.1) will be brought together with the H-O-T approach. Then, suggestions as to choosing the adequate Open Innovation method(s) depending on the respective characteristic values of the SME will be offered. The following Fig. 1 illustrates this idea.

In this paper, two examples for types of SMEs and the resulting suggestions concerning the implementation of Open Innovation methods will be described.

The first type of SME is a traditional managed enterprise. The entrepreneur is very risk averse and adheres to his traditional views and procedures. New technologies – like web 2.0 – are not used in his SME. According to the H-O-T approach the levels human and technology aspects inside the enterprise are not compatible with the changes outside the enterprise. Probably, the employees are not sensitive to the identification of useful external knowledge. Hence, it is not advisable to start an open appeal to an undefined network of contributors. Therefore, some kind of Lead-User-workshop would be advisable. The SME should invite some customers or suppliers and discuss a special product – existing or prospective.

The second type of SME is managed by an entrepreneur, who favours and exemplifies an open organisational culture. New technologies are used in all departments. His employees work in interdisciplinary teams and the communication between the teams is assisted for instance by periodical meetings. Due to the knowledge and use of new information and communication technologies it would be possible to implement a virtual community or an internet platform to start idea competitions. The open communication inside the SME will support the process of separating and implementing usable external knowledge.

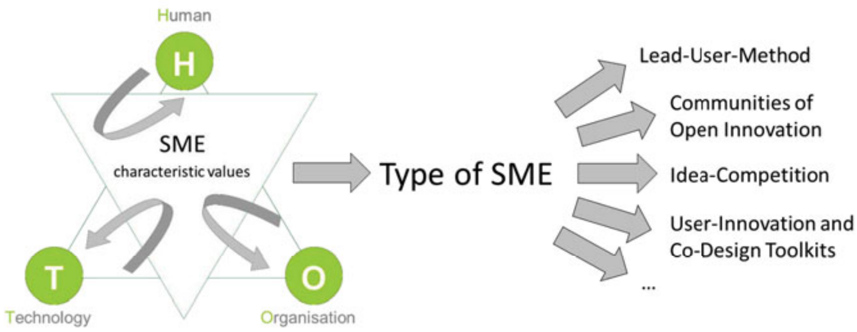

Fig. 1 Supported process of choosing Open Innovation adequate methods

These two types of SME are just examples. A lot of other aspects have to be considered. The type of customer contact is another important factor for a recommendation concerning the implementation of Open Innovation methods. It is also possible to use modifications of Open Innovation methods in some SME.

4 Conclusion and Outlook

In the face of globalisation, the pressure to be innovative has been increasing exponentially. Especially SMEs must prove a high innovation ability in order to be competitive. Open Innovation provides new methods and approaches to the innovation process. With Open Innovation, SME get better access to information about need and respective solutions. Given this fact, SMEs receive the chance to improve the efficiency and effectiveness within their innovation processes. Several research projects have already generated some methods for the implementation of Open Innovation methods. These methods generally focus on the human and technology aspects. But a method which supports the changing process of an SME's organisation – which includes the enterprises' structures and processes – is still missing. SME need to be prepared for a generation of younger people who accept technical innovations and operate in virtual worlds. Their point of view with regard to tradition and their adherence to standards do not represent the same anymore as they used to in traditionally led enterprises. Instead, SMEs receive an adaptable, highly capable of multi-tasking, collaboratively working type of human.

The conception of Sect. 3.2 is just one part of the tool to control Open Innovation in SMEs. Before matching the SME's characteristic values with the H-O-T approach and choosing the adequate method(s), the SME has to decide whether it should use Open Innovation or not. This part will be based on the use-oriented cost-effectiveness evaluation by Weydandt [Wey00]. Furthermore, a third part has to facilitate an ex-post target-performance comparison. These last ideas will have to be followed and put to practice in the next years.

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Modular Software Architecture Approach for a Telematic Rescue Assistance System

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Abstract German emergency medical services are in need of new solutions to their care system in order to cope with raising mission numbers and a reduction of available physicians for emergency care. As countermeasure to this development the research project TemRas investigates the introduction of a Telematic Rescue Assistance System. Supported by this system, physicians located in a teleconsultation center advise multiple paramedics teams during their emergency missions. Usage of this system must be unobtrusive for the supported paramedics in order to enable optimal patient care. The proposed software architecture addresses this by enabling a seamless integration of existing medical devices and their communication protocols for real-time data transmission between emergency scene and teleconsultation center. To ease the integration of the resulting heterogeneous application infrastructure in the teleconsultation center, a message bus is introduced which provides a qualified integration point for such environments.

Key words: Telemedicine, Emergency Medical Services, Software Architecture

1 Introduction

German *Emergency Medical Services* (EMS) are experiencing increased mission numbers combined with a shortage of trained EMS physicians especially in rural areas. This development threatens the quality of patient care in the established German two-tiered EMS model where *Mobile Intensive Care Units* (MICUs) – each consisting of an ambulance vehicle staffed with two paramedics – are supported by EMS physicians if need is indicated [BHM08]. The German research project *Med-on-@ix* provides a possible solution for this problem by investigating how to sup-

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port paramedics in patient care while an EMS physician has not yet arrived on the emergency scene [SBR+09]. The support is given by means of a *Telematic Rescue Assistance System* (TRAS) enabling skilled EMS physicians located in a teleconsultation center (hereafter called tele-EMS physicians) to be provided with patient vital signals, auscultation data, photos, real-time video and bidirectional voice communication from the emergency scene [PGH09].

Research objectives in the project *Med-on-@ix* focused mainly on the following aspects:

- Testing medical support capabilities of such a TRAS
- Defining requirements for TRAS
- Implementing a TRAS prototype for evaluation which enables the support of one MICU by one tele-EMS physician.

During the one year evaluation phase at the end of the project *Med-on-@ix*, the supported MICU was accompanied by an additional EMS physician to secure patient care, allowing for the introduction of additional equipment and to reduce requirements on the TRAS concerning application usability. In August 2010 the follow-up research project *TemRas* started, targeting the following aspects:

- Refining the medical support processes
- Advancing the developed TRAS in order to enable simultaneous support of multiple MICUs
- Preparing system design for a possible commercialization of the TRAS.

A field test with the duration of one year will be performed at the end of the project *TemRas*. During this field test two physicians will be on duty in the teleconsultation center, advising five MICUs – this time without being accompanied by an additional, dedicated EMS physician – in their day to day missions.

The major challenges addressed by the TRAS' adapted software architecture concern the absence of standards for data exchange or compliance with these standards by existing devices used by MICUs as well as to manage the communication for different applications. The development of the TRAS software architecture presented in this paper is based upon the architecture designed in project *Med-on-@ix* but follows a new modular approach to cope with these problems. Based on other approaches to TRAS architectures and related considerations, the new approach of the TRAS architecture is presented in this paper.

2 Related Work

This section gives a brief overview of the software architecture designed in the project *Med-on-@ix*. It also discusses related approaches to the problem of connecting devices located at an emergency scene with a teleconsultation center for remote diagnostics, which is the main focus of most published work addressing TRAS software architectures. A short discussion motivates the new architecture approach presented thereafter.

The software architecture used in *Med-on-@ix* as described by Protogerakis et al. [PGH09] is based upon a hybrid middleware combining messaging and streaming transports to connect all system components. The middleware uses *Remote Procedure Calls* (RPC) implemented with the help of the object oriented framework *Internet Communication Engine* (ICE) by vendor *ZeroC* for communication between different peers. A robust *Internet Protocol* (IP) network, connecting emergency scene and teleconsultation center, is realized by using multiple mobile network links combined with multipath routing [HB07]. This middleware concept facilitates the use of dynamic compression and data prioritization settings depending on mobile network quality. An inherent drawback of this approach is that all client applications have to be adapted to the middleware's interfaces or adaptors have to be provided to connect a device with the middleware. To avoid this drawback is the major focus of the new, modular architecture approach described in this paper.

Another approach presented by Shaikh et al. [SMMM09] focuses on a service oriented architecture using XML messages and the *Simple Object Access Protocol* (SOAP) to connect mobile clients to central diagnostic facilities. This design does not cover the transmission of real-time data like video, voice calls or continuous vital signals. Likewise, Lamberti et al. [LMSZ03] propose the use of web technologies like XML messages and XSLT transformation to interchange information between mobile clients, in-hospital workstations and storage services. The usage of existing standards for medical data exchange including *Vital Signs Information Representation* (VITAL, ENV 13734) and *Digital Imaging and Communications in Medicine* (DICOM, ENV 12052) eases the integration of Hospital Information Systems for information exchange.

Pavlopoulos et al. [PKB$^+$98] proposed and successfully tested a preclinical EMS support system using a single *Global System for Mobile Communications* (GSM) channel for medical data transmission and a second one for voice communication. Similar to the approach of Protogerakis et al. [PGH09], client devices were interfaced to enable communication via a specific *Transmission Control Protocol* (TCP)/IP based application protocol. Connection losses are reported to be a major problem in this setting.

Alesanco and Garcia [AG10] address the issue of real-time *Electrocardiography* (ECG) data transmission over unreliable mobile networks by proposing a new communication protocol on the application layer using *User Datagram Protocol* (UDP) at the transport layer. They conclude that TCP transports over a 3G mobile network channel are not suited for real-time transmission of ECG waveforms.

Common to the described approaches is the need for client applications and devices to be able to directly communicate with the middleware either by implementing its interfaces or via special adapters understanding both, the client's and middleware's interfaces. At this layer, standards as used by Lamberti et al. [LMSZ03] play an important role to reduce the need for application and device adaption. RPC mechanisms like SOAP or as used by ICE provide only limited support for the addition of new functionality without the need for major modification of existing applications. Instead, the use of a message bus for such scenarios has been established with the advent of *Enterprise Integration Patterns* [HW04].

3 Modular Architecture Approach

3.1 Brief Requirements Summary

Protogerakis et al. [PGH09] presents basic requirements which guided TRAS development in the project *Med-on-@ix*. To continue the TRAS development, an initial requirements adaption has been performed, following a participative development approach as described by Schneiders et al. [SSJ11]. The resulting major improvements which have to be provided by *TemRas* can be summarized as follows:

- An integrated working environment is required, which automatically connects the applications used by the tele-EMS physician to the devices of the MICU he/she currently supports.
- A highly automated documentation system that gathers as much data from the diagnostic devices as possible and that queries missing information from the tele-EMS physician.
- The MICU's paramedics cannot be equipped with burdensome additional equipment compared to their usual equipment outside of TRAS implementation: Vital signals measurement unit must be integrated into the defibrillator; communication units providing data and voice connection between the paramedics on-scene and the teleconsultation center must be miniaturized; no tablet computer or comparable notebook can be carried by the paramedics.
- The TRAS should be integrated seamlessly into the MICU's equipment in order to avoid additional workload for the paramedics by introducing the TRAS.

3.2 Software Architecture

The new architecture addresses the new requirements posed on devices which are used on the emergency scene by facilitating the usage of existing diagnostic devices without requiring their adaption to a common middleware. This differs to existing approaches which require the adaption of devices to communication protocols enforced by the middleware. The following aspects form the modular architecture approach's core:

- Enabling transparent usage of proprietary communication protocols to connect endpoints between the emergency scene and teleconsultation center without the need for adaption to the middleware
- Providing an easy integration point for components with the middleware to allow their automatic control for mission management without enforcing the need for integration.

All real-time data streams for continuous vital signals transmission, auscultation recordings, video and bidirectional voice communication will bypass the middleware, dissolving the need for handling streaming in the middleware. *Quality of*

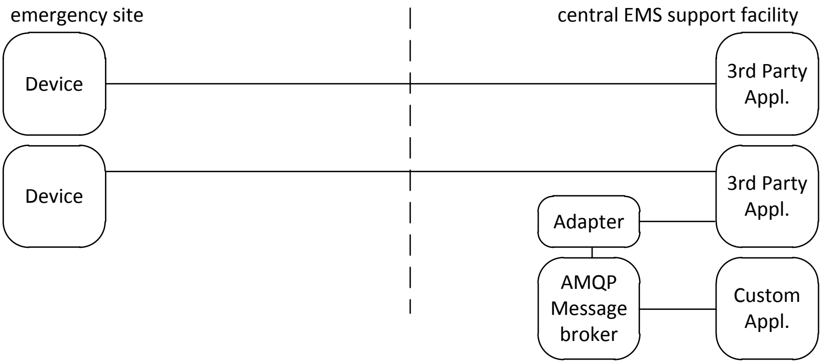

Fig. 1 Modular architecture approach for transparent connection of 3rd party devices

Service features, that Protogerakis et al. [PGH09] intended to be handled by the streaming part of the middleware, will either be performed on the transport layer of the data links between emergency scene and teleconsultation center or directly by the applications if supported.

This reduction of responsibilities for the middleware facilitates the use of existing messaging solutions to handle mission management, mission documentation and application control. A message broker using the *Advanced Message Queuing Protocol* (AMQP) was chosen as central message bus of the middleware to promote the use of open standards. This provides a simple integration point for software components and likewise 3rd party applications if their integration with the middleware is desired. This concept is depicted in Fig. 1.

The robust IP network, which already has proven its practicability in project *Medon-@ix*, forms the basis for the transparent usage of proprietary communication protocols. The *Mobile Communication Units* establishing the network via multiple mobile data links are undergoing miniaturization and enhancement to enable the simultaneous support of multiple emergency scenes.

Applications used by the tele-EMS physician have to be compatible with the existing communication capabilities of devices used on the emergency scene. In many cases, this requires the usage of proprietary applications which has the advantage of using existing and proven software in the teleconsultation center. A drawback is the missing standardization for the integration of these applications into the tele-EMS physicians' workplaces to allow the required degree of automation. In the short term, individual solutions for this integration have to be implemented. A standardized component model which allows the embedding of different 3rd party applications into an automation framework would provide a solution for this problem.

4 Conclusion

A new approach to TRAS software architecture is presented that facilitates modularity by providing a qualified integration point for optional integration – instead of enforcing the connection of devices and applications to a common middleware. A major advantage of this heterogeneous approach is the simple usage of existing medical devices and applications. The targeted goal to deliver an integrated working environment to tele-EMS physicians currently requires the integration of 3rd party applications by different means. Open standards for the communication with medical devices or a standardized component model for the data displaying applications would diminish this need. The development as well as the establishment of such standards is an important task for future work in this research area.

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Emergence of Innovation

Eleven Strategies to Increase Innovative Capability

Sven Trantow, Alan Hansen, Anja Richert, Sabina Jeschke

Abstract The economic situation of today forces organizations to innovate on a continual basis. Therefore the central aim of a sustainable management of innovation is to increase the innovative capability of a company in order to establish a system of continuous innovation. The article deals with the fundamental questions of the nature of innovation and gives a holistic view of how innovations emerge in enterprises. Against the background of central dilemmas of economic acting, it describes eleven transdisciplinary and practice-oriented strategies for companies to cope with the dilemmas, strengthen their own innovative capability and so establish a system of continuous innovation. The following insights are intermediate results of the German research and development project "International Monitoring" (IMO).

Key words: Innovative Capability, Innovation Strategies, Economic Acting, Dilemmas, Innovation Management, Modern Working Environment

1 Introduction

What enables enterprises to continuously induce innovations? Against the background of rising pressure to innovate within the world of economy and work [RS10] this question plays an increasingly important role. When looking for an answer, approaches from traditionally process and output-oriented innovation management [MD09] are only of limited help. Oriented mainly on product development phases, these concepts do indeed support an individual innovation process, but do not show what preconditions have to be met in order to have an organization continuously – not only punctually – initiate innovation processes and induce innovations. On today's saturated global markets this very capability to innovate continuously

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is advancing to be the decisive competitive factor. The realization of one – or even more than one – good idea is not enough. Enterprises have to innovate permanently and create differences e.g. concerning their products, operation or business models in order to be and stay economically successful [Hub05]. To establish a sustainable innovation management therefore means to establish a system of continuous innovation by boosting the companies' innovative capability.

The research and development project "International Monitoring"[1] (IMO) funded by the German Federal Ministry for Education and Research (BMBF) and the European Social Fund (ESF) monitors and analyzes transdisciplinary insights on the topic of innovative capability. One main focus lies in the analysis of specific conditions and areas of tension (dilemmas) of the modern work environment and on the identification of strategies that can help especially small and medium-sized enterprises (SME) to manage these dilemmas and strengthen their innovative capability. By means of various instruments of knowledge monitoring[2] the IMO project has identified *five dilemmas* as central challenges of economic acting and countered them with *eleven organizational strategies* to cope with these dilemmas and to strengthen the capability to innovate constantly.

The present article deals with the fundamental questions of the nature of innovation and their generation in enterprises. The following article firstly asks the basic question what innovations are how they emerge in organizations. Against the background of the identified dilemmas it describes eleven transdisciplinary and practice-oriented strategies for SMEs to cope with the dilemmas, strengthen their own innovative capability and so establish a system of continuous innovation.

2 Two Necessary Criteria for Innovation

What is innovation? In spite – or even because – of the omnipresence of the term innovation on scientific, economic and political levels there is no unified idea of its meaning. The certainty that innovation is the key to long-term global competitiveness seems to be equally strong as the uncertainty about what sort of key we are looking for:

> It only seems appropriate that, in times of economic challenge, global competition, and an overabundance of similar products and services, leaders would turn to innovation as the new corporate mantra. Unfortunately, the concept of innovation has been so widely used and misused that many people are now confused as to what it really is. [Dun02]

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[1] The IMO Project is carried out by the institute cluster IMA/ZWL & IfU of RWTH Aachen University. The project runs until 2012; accordingly the findings described in the article are preliminary results. Further information on the project can be obtained online at www.internationalmonitoring.com

[2] For its transdisciplinary monitoring activities the IMO Project uses e.g. national and international expert study groups, innovation workshops in German SME, online questionnaires, in-depth interviews, virtual conferences, expert reports and trend studies, as well as summer and winter schools.

To make the notion of innovation a little more palpable we most of all need essential criteria that help to distinguish whether something is an innovation or not. For the purposes of this article two criteria seem sufficient:

- Quality of profit, and
- Long-term effectiveness.

In order to elaborate on these two criteria it seems convenient to start out from a definition of innovation as general as possible. Stephen Lundin has given such, and defines innovation as "fashioning something new and of potential value from a novel idea" [Lun08].

An innovation thus has to show some kind of "potential value". The criterion quality of profit now scrutinizes in more detail what sort of value is in question here. As defined by Schumpeter [Sch34], traditionally the economic benefits and, as the understanding of innovation in the past has been highly product-oriented, primarily monetary profits and marketability have been addressed [Wit10]. Still, during the transition from industrial to knowledge and service society an increasingly holistic notion of innovation establishes itself that integrates a multitude of other sorts of innovation besides product innovation [THJ11, Gar10].

The increased importance of e.g. social, cultural, scientific and organizational innovation [HJ10, Now08, Ram10, Ram09] leads to a decreasing importance of economic criteria to assess innovation. Social innovation, for example, which in the end are always aimed at fundamental changes in human behavioral patterns [HKS08], can neither be sensibly assessed with criteria of market launch nor with monetary profit. Neither do organizational innovations always aim at increasing corporate performance or at a better efficiency of production processes. The implementation of occupational safety and health regulations as well as the establishment of environmental standards are primarily focused on the augmentation of social resp. ecological sustainability. Marketability and economic success by themselves therefore cannot do justice to an expanded and holistic understanding of innovation. The quality of the profit coming from an innovation can be of an economic, but also of a social and ecological nature.

The criterion long-term effectiveness now introduces a temporal component that has not been mentioned in Lundins definition but is introduced here as an essential criterion. After all, not every new and realized idea becomes an innovation overnight. Thus, if one wants to know what an innovation is one always simultaneously ask the question when an innovation is. Already Schumpeter made clear that innovations are not snap-shots or flash lights but exhibit a far-reaching impetus for change – like the often cited transition from stage-coaches to railways [Sch34]. New products, however technologically advanced they are, do not simply become innovations by being placed on the market – they have to establish themselves for a longer time so that their impetus for change can take effect. The same is to be said for all other kinds of innovation. The fact that it can never be determined a priori but only in retrospect whether something is or is not an innovation is less a disadvantage of the long-term effectiveness criterion but rather a fundamental characteristic of the uncertainty of innovation: "The insecurity inherent in innovation corresponds to the openness of the future" [Now08].

Combining the illustrated criteria quality of profit and long-term effectiveness, the term innovation becomes a bit more concrete and can be described in a holistic sense as follows:

Innovation is the realization of new ideas that contribute to sustainable changes.

3 Innovation as an Emergent Phenomenon

Generally speaking, there are three different types of answers to the question how innovations come to be:

- A human-centered perspective
- An organization-centered perspective
- A technology-centered perspective.

The human-centered perspective starts out from the viewpoint that people are the "sole source of innovation" ([Klo04], translated by author). In this sense the innovative capability of any organization only depends on the innovative capability of its employees [Lun08].

The organization-centered perspective focuses on corporate processes and structures to explain the genesis of innovation. By means of best practice examples [PW04, Gun11], process-oriented models of innovation management [TB09, Coo10] and theoretical concepts like organizational learning [AS95], absorptive capacity [CL90] or dynamic capability [Tee09] general characteristics and instruments of innovative organizations are unveiled.

For the technology-centered perspective innovations emerge primarily as developments of new technological possibilities. This perspective especially underlines the connection between innovation and research and development activities. Here, the technological type of innovation serves as a paradigm and is accorded a higher relevance compared to all other types of innovation [Ram10].

The three depicted perspectives have in common that they do offer explanations and controlling possibilities for generating innovations, but in detail run into danger of simplifying the complex emergence conditions and thus to distort the characteristics of innovation. Innovation is neither the mere realization of creative ideas nor simply a result of technological development processes or organizational properties. The World Wide Web, for example, would certainly not have been innovated by CERN in Geneva if human, organizational and technological aspects had not colluded. In fact, one of the most influential innovations of modern times emerged explicitly from the interweavement of the specific intra-organizational problems of chaotic information flow at CERN, the extraordinary competence of Tim Berners-Lee and the technological achievement of hypertext [Ber89]. To limit the genesis of the World Wide Web to one single of these dimensions would be equal to a reductionist fallacy.

In order to establish a holistic understanding of innovation and thus to make possible a holistic management of innovation an integration of the described perspectives and consequently the observation of the complex interrelationships of all relevant human, organizational and technological aspects is necessary [HHL09]. From a holistic and system-oriented perspective innovation is always the result of the fundamental interdependence of these dimensions and of the processes resulting from them. Innovation therefore has to be regarded as an emergence coming from the whole socio-technological system that induces it. The fact that this system can neither be mastered nor accurately controlled is mirrored in the insight that innovation is not plannable and controllable, either [Now08, Sch06]. Against this background a sustainable innovation management is not simply oriented on processes of product or technology development. It does not start with generating ideas, but first of all asks what human, organizational and technological developments have to be created in order to make a system continuously induce innovation and to reach a high degree of innovative capability. In this sense, one can record:

The innovative capability of companies comprises the complex interrelationships between the human, organizational and technological requirements to continuously induce innovations.

Whilst taking into account the outlined characteristics of the notion of innovation the description can be specified:

The innovative capability of companies comprises the complex interrelationships between the human, organizational and technological requirements to continuously induce and realize new ideas which contribute to sustainable changes.

4 Obstacles on the Way to Innovative Capability: Dilemmas of Economic Acting

Shadowed against today's pressure to innovate, innovative capability has become one of the most important success factors for sustainably safeguarding the competitiveness of enterprises and whole economies [DEKS06]. To increase the innovative capability, organizations need holistic and practical strategies that are oriented towards real-life challenges of economic acting. In order to describe the main challenges for companies on the way to strengthen their innovative capability the research and development project "International Monitoring" (IMO) has identified *one meta-dilemma* and *four corresponding dilemmas* that constitute elementary problems of economic acting in general and for innovative capability in particular [HTH10].[3]

[3] Basis for the identification of these dilemmas was an online-survey of German and international experts dealing with the topic of innovative capability [BSH09].

Thus, the *meta-dilemma* of today's world of work and business lies in the incompatibility of the doctrine to maximize short-term profits and the principle of sustainability – a contradiction that is rooted in two basic assumptions of economic acting:

- On the one hand the (neo-)classical reduction and concentration of entrepreneurial goals onto maximizing one's own monetary profits [Fri70]. This radically market-oriented maxim in today's fast-moving financial and economic systems is joined with a breathlessness of acting stemming from constant pressure to succeed. In this perspective, enterprises pursue purely economic goals.
- On the other hand the understanding of the limits of growth and the resulting demand for responsible economic action that safeguards a sustainable global system [MRM05]: The future-oriented principle of sustainability crosses traditional boundaries between disciplines and pursues a holistic approach that extends the economic perspective by social and ecological views. Here, the growing global consciousness for environmental and social affairs does not only lead to a revival and integration of the notion of sustainability, but increasingly appreciates sustainability as a competitive advantage of itself [Mic06].

The reductionist principle of (short-term) realization of maximum profits forces economic subjects to act ruthlessly and is inconsistent with anticipatory, responsible and permanently successful management [Thi09]. This is why the meta-dilemma of economic acting denotes one of the most fundamental problems when dealing with management tasks in profit-oriented areas of economy.

On the background of organizational innovative capability this action-immanent conflict can be described by four dilemmas which are characterized on the one hand by necessary prerequisites for sustainably innovative enterprises and on the other hand by decisive dimensions of economic pressure in everyday business:

- Responsible use of human resources vs. cost pressure
- Long-term strategies to increase innovative capability vs. pressure to succeed
- Time for learning processes vs. time pressure
- Need for stability vs. flexibilization pressure.

These dilemmas illustrate main challenges economic actors in today's world of work and business have to manage. Their fundamental structural feature is that they cannot be completely resolved or eliminated. The four dimensions of economic pressure are constitutive for a market economy. They are essentials of a healthy and productive competition and as such they are drivers of economic performance and dynamism. Therefore, the real challenge for economic actors is not to eliminate them, but to find appropriate strategies to manage the dilemmas efficiently and thus to increase the innovative capability of companies in a sustainable way.

Subsequently we will first outline the dilemmas and their basic characteristics. Section 5 then will introduce eleven strategies for SMEs that help to manage these dilemmas. Figure 1 gives an overview of the dilemmas and the corresponding strategies.

Fig. 1 Overview of organizational strategies to increase the innovative capability of a company against the background of central dilemmas of economic acting.

4.1 Dilemma 1: Responsible Use of Human Resources vs. Cost Pressure

The dilemma describes the requirement for a comprehensive, prospective and responsible management of personal knowledge potentials, skills and competences under simultaneous economic pressure to cut expenditures. This challenge consequently is located within the social dimension of the question of sustainability and primarily, but not exclusively, relates to how organizations deal with human potential.

Overcoming with a purely technology-centered and product-oriented approach toward innovations enhances the value of immaterial factors within innovation processes. With the notion of innovative capability people and consequently social processes as decisive enabling factors of innovations increasingly get into focus. The transition to a knowledge and service society makes people as carriers of knowledge and skills become a highly important innovative and competitive factor. In contrast to this increased appreciation of the human factor organizations faced with increasing cost pressure still often resort to reduction of labor cost and short-term profit maximization instead of aiming for sustainable safeguarding the future. The paradigm change in the perception of the employee from yesterday's cost factor to today's asset has by far not been implemented into economic practice yet.

4.2 Dilemma 2: Long-Term Strategies to Increase Innovative Capability vs. Pressure to Succeed

The dilemma describes the increasing demand for basic structural and processual changes in organizations to strengthen innovative capability while being faced with the necessities of quick success. Here, success must not be measured in purely financial terms, but as a general correspondence of the results of long-term change processes with the individual target settings.

Management reasoning often remains reductionist and figure-oriented, leading to the fact that soft factors of organizational changes that foster innovative capability bear only little weight in decision processes. Still, complexity and dynamics within the working world as well as the importance of intangible assets are increasing. Consequently new approaches and methods are necessary to give answers to the central question of how economic decision-making has to adapt to complex change processes.

4.3 Dilemma 3: Time for Learning Processes vs. Time Pressure

The dilemma describes the individual and organizational necessity for learning and development processes under conditions of increasing time constraints on work. On the one hand it addresses time pressure for the individual leading to stress, insecurity and growing psychological strains right up to Burnout syndrome. On the other hand, enterprises faced with globalization, growing dynamics and a flexibilization of economy also have to deal with increasing time pressure in their operative everyday work. This often shows in neglect of development and change processes, a lack of customer service or in an innovation-hampering corporate culture. Here time pressure, especially on the organizational level, mirrors the economically determined pressure for success, cost reduction and flexibilization.

As innovations decisively depend on the human potential of employees and the readiness of enterprises to evolve, a lack of learning processes resulting from time pressure in operative tasks constitute considerable obstacles to innovative capability. Against this background, the individual is faced with the question of compatibility of working and learning under the tight conditions of a modern work environment. From the entrepreneurial view, new ideas on integrative design of learning and working environments are necessary. They have to allow for both a responsible and innovation-friendly handling of human resources and the adaptation of organizational processes and structures to new requirements in globalized economy and a changing work environment.

4.4 Dilemma 4: Demand for Stability vs. Flexibilization Pressure

The fourth dilemma describes the demand of individuals and organizations for safety of current and planning of future processes. At the same time they face an increasing economic and social pressure towards continuous change, permanent adaptation and the according disintegration of existing structures. Besides the structural perspective of flexibilization the dilemma also focuses on the processual view of dynamics, acceleration and change.

The effects of increased flexibilization for the working and private life of individuals are serious, from general social acceleration to individual psychological illness. Still, flexibility is the prerequisite for a maximum of capacity to act, self-determination, freedom and creativity – highly important characteristics when dealing with uncertainty that is inseparable connected to innovation. This is why it is all the more crucial to find a balance between flexibility and stability as well as between dynamics and deceleration.

5 Innovation Strategies for SMEs

Against the background of the stated main challenges of economic acting this section outlines eleven strategies that especially SMEs can apply to manage these interdependent dilemmas and strengthen their innovative capability. There are two reasons why the particular focus on SMEs is of special interest. Firstly, small and medium-sized enterprises are the protagonists for innovation success in Germany [DJB+07]. However, despite their major importance and their enormous number – 99,6% of all enterprises in Germany are SMEs [fM09] – there are only a very few studies focusing on innovation in SMEs [Neu08]. Secondly, the tight resource allocation of SMEs compared to large enterprises (e.g. equity base, strategic business development, bandwidth of qualifications and employee competences, outside networks, systematic market observation) entails that SMEs are forced to optimally identify and utilize their innovation potential through adept strategic acting. Their success is decisively dependent on whether it is possible to create innovation-friendly framework conditions that significantly support the emergent character of innovations. How exactly these framework conditions look like can only be determined through taking into account the specific characteristics and circumstances of the individual enterprise. Management therefore is required to identify fitting strategies for their individual business situation and to implement them into everyday working life via concrete measures.

In this sense the following eleven strategies identified by the “International Monitoring” project serve as an orientation aid or navigation map to increase the innovative capability of organizations:

1. Health and Prevention Management
2. Establishment of Innovation Cultures
3. Use of Knowledge and Human Potential
4. Holistic Innovation Management
5. Fostering Social and Organizational Innovations
6. Opening of Innovation Processes

7. Continuous Competence Development
8. Integrative Design of Work and Learning Environments
9. Work-Life-Balance
10. Innovative Forms of Work Organization
11. Management of Uncertainty.

Subsequently, these strategies will be described in detail. At the same time, we will elaborate on their importance for corporate innovative capability and derive some recommendations for action to implement these strategies into entrepreneurial practice.

5.1 Health and Prevention Management

Increasing flexibility and dynamism in the modern working environment and the associated acceleration and complexity of working processes are tough challenges for the physical capacity and psychical resilience of employees. At the same time, companies are faced with the task of matching working requirements with the needs of an ageing workforce due to demographic change [Zai08]. Occupational health and prevention management can partially absorb these effects. On the one hand, it encompasses a design of everyday work that advances and protects employees. On the other hand, it is aimed at personnel progress and competence development in order to sustainably preserve employability, creativity and innovativeness. The maintenance of health thus has to be integrated into the vision and culture of companies as a decisive strategic factor for innovative capability.

Today, many types of physical and mental illnesses can be significantly reduced through measures for health maintenance [WHO05]. Nevertheless, their strategic implementation has a relatively low priority in current company practice [HKH07]. Only close to a fifth of all businesses thus actually carry out measures for maintaining health within their organization. This figure is alarming especially against the background that periods of absenteeism due to (chronic) illness and lack of motivation are both on the increase [Ric09]. In the medium term this development leads to economic under-performance and an absorption of the innovative capability that consequently cause considerable financial burdens in the companies concerned.

In many cases health and prevention management is not taken seriously because it monetarily only pays off in the long run. However, it covers much more than protection against the flu or safety in the work place. It can be seen as a partial strategy, which is integrated in the overall corporate and innovation strategy on the basis of health reports [Pfa08]. Through the linking of various internal and external pieces of information in the health report (e.g. effectiveness of measures, available resources, individual stress levels), recommendations can be derived for presenting to decision-makers in companies (ibid). Findings on physical complaints are taken into account in this process in exactly the same way as psychic imbalances, to which many long-term health problems can be attributed. For health and prevention programs to achieve the desired success, they must be built on the participation, conviction and willingness of the employees.

Starting from these findings, Meyer (2006) [Mey06] proposes a 3-phase concept, which introduces a health and prevention management in three stages: Short-term health management primarily comprises the recognition, elimination and avoidance of current illnesses and accidents through behavioral and situational prevention [HKH07], e.g. regarding to the workload and work organization. Medium-term health management aims at encouraging the employees to adopt a consciously sustainable and healthy lifestyle, e.g. through corporate leisure activities. Long-term health management is above all targeted at the avoidance of physical long-term consequences and psychic problems especially by establishing a corresponding company culture.

5.2 Establishment of Innovation Cultures

Innovative capability and a system of continuous innovation, especially in SMEs, are built on an organizational culture of innovation:

> The only thing which cannot be copied and which is simultaneously a breeding ground for producing new successful product, service and business models again and again is the culture of innovation of a company. And it is also a very important factor in marking out companies in the fight to recruit the brightest candidates. ([JZ09], translated by author).

In order to draw up measures for establishing an innovation culture, the current company culture needs to be investigated as systematically as possible and be focused on the overarching company strategy. This is because without considering the underlying cultural mechanisms of any company, unexpected and highly undesired consequences can occur. Cultures are formed as the linking element of the members of a group, looking for a purpose and integration. Every company culture is therefore made up through a pattern of common basic premises, which the group has learnt to adopt when mastering their problems, which has been shown to succeed and is thus accepted as binding: and which is therefore passed on to new members as rationally and emotionally the correct approach for dealing with such problems [Sch10]. Innovative cultures are subcultures within the company culture, which define precisely those specific basic assumptions, values, capabilities and norms related to coping with innovative tasks and which are shared by the majority of members of the company staff involved in the process of innovation.

A key aspect of an innovative culture is the avoidance of obstacles. In optimum circumstances, the company promotes bottom-up innovation processes and thereby encourages its employees to participate in developing innovations and sets up promoters' networks, which increase the probability of innovations succeeding [KK07]. Innovations cannot continuously be generated top-down. The genuine force of innovation comes from below. That is why in an effectively operating innovative culture, it is possible to advance all kinds of ideas, irrespective of where they are coming from [JZ09]. In this context, the middle management has a key role because it operates as multiplier of visions and stimuli within the whole company.

The establishment of a professional error management system in which mistakes are constructively tolerated and not sanctioned [JZ09] is a prerequisite for an effectively operating innovation culture. It ensures that the organizational structures are focused in such a way that they encourage and do not hinder creativity and the implementation of ideas.

The generally observable trends towards internationalization and globalization necessitate the formation of multi-cultural teams of various kinds. Innovation or project teams should consequently be distinguished by a mixture of various personnel profiles and roles due to this development. The company management should likewise promote inter-cultural cooperation to use diversity as a source of innovation, while the needs of employees from abroad should be ascertained and taken into account [Sch10, WSH07, SN96]. Especially SMEs are faced with a particular challenge in this regard due to increasing internationalization and a frequent lack of international experience [JZ09].

Innovations today are no longer driven forward just by the creativity of the members of an organization. They are much more the result of a new quality of cross-linkage, within as well as outside the company. The innovative organization is thus no longer split into parts divided against each other, but is integrated and thus unites people in a permeable and transparent structure, e.g. through the establishment and authorization of internal and external networks, the cooption of representatives from all departments involved in the process (cross-functional cooperation) or the systematic surveying of customers' opinions [JZ09, TS07].

5.3 Use of Knowledge and Human Potential

Knowledge and human potential are highly important factors for the company's success in innovating. As part of the shift from an industrial to a knowledge and service society, and due to the lack of skilled workers in consequence of the demographic change they rapidly increase in value and become the decisive drivers for innovation processes [AHM05, Sam06]. Against this background, it is no wonder that intellectual resources have already become the most valuable assets of a company [Edv97]. A systematic and targeted use of these intangible assets and an associated sustainable management of human resources are therefore key factors to strengthen the innovative capability of a company. In the long run, only such companies will be successful, which succeed in systematically generating competitive advantages from the utilization of their internal resources [SvdBH09].

Investments into the immaterial assets of an enterprise have to be regarded as substantial leading indicators for the sustainable success of the enterprise on the market. Depending on the branch of the enterprise one can calculate with a lead time of about four years until misguided developments in immaterial assets express themselves in the commercial viability and thus in corporate results. Dealing successfully with intangible assets thus forces at least a medium-term perspective of all management activities and requires holistic management approaches [Nag09]. An Intellectual Capital Management (IC-Management) is dealing with the systematic use and management of intangible company resources. It aims at identifying, structuring and evaluating currently available intangible assets in order to use this information for strategic decisions and measures for organizational development.

Intellectual capital is based on a holistic understanding of immaterial assets and consists of person-related human capital, organization-linked structural capital and intermediary relationship capital [KL08, BB03]. Human capital comprises the knowledge, skills, competences and behavioral patterns of all employees of a company like qualifications, social competences, motivation or leadership skills. Structural capital indicates all organizational structures and processes that are used to accomplish everyday working tasks. Examples for structural capital are corporate culture, cooperation and communication processes or technological infrastructures. Relationship capital contains all external stakeholders that play a role in business activities of a company, such as customer and supplier relationships, cooperation partners or investors.

One main target of IC-Management concepts is the interlinking of human capital and structural capital [BB03] so that it is possible to transfer person-related knowledge in structural capital on the one hand, and to use the structures of the company for the strategic development of the human capital on the other hand. Within this process, not just the use of knowledge and human potential is the focus of consideration, but also the creation of working conditions which promote learning and therefore a further development of these resources.

Managing the intangible assets resp. the intellectual capital of an organization is a decisive factor for its innovative capability and an important indicator for sustainable competitiveness in knowledge and service societies. To meet the requirements of a holistic approach, it is necessary to integrate the IC-Management in currently existing management concepts [Nag09].

5.4 Holistic Innovation Management

Science and business are in agreement that the skill of innovating must be understood as a complex, multi-dimensional concept, representing a phenomenon spanning the entire organization [Sch09, Sam06]. Innovative capability must accordingly be understood on the basis of the complex interrelations of all relevant human, organizational and technological aspects of a company – including market- and technology-related changes as well as environmentally caused changes [Koc07].

Although holistic innovative management is increasingly being identified as the decisive factor in any long-term company strategy for increasing innovative capability, decision-makers in SMEs still tend to focus on a traditionally technology- and product-oriented perspective on innovations, largely excluding the human and organizational dimension [HTH10]. Failing to recognize the linkages of human, organizational and technological aspects as well as the interdependent processes resulting from these complex interactions inhibits the innovative and competitive capability in the longer term. As these multi-layered processes can only be planned, controlled or foreseen to a very limited extent, this means that conducting innovative management holistically is all the more difficult.

In order to establish a holistic perspective on innovative processes, including the human and social components as well as organizational operating and working conditions as of equal importance, companies must create the conditions which enable a system to continuously induce innovations [THJ11]. The success or failure of innovative activities is crucially determined by the value placed on innovation processes by the management of a company.

For this reason, the management level needs to promote and esteem creativity and ideas throughout all levels of staff as well as undertake on-going investments in organizational modifications. It is important to create operating conditions which promote innovation to make use of the human and relational capital of all actors at every single level within a hierarchy. Successful innovative management processes which focus on the holistic picture further encompass the clear definition of strategies and targets, rapid decision making as well as the establishment of sustainable social.

The close linkage and agreement of the company strategy with the innovative strategy should likewise be obvious within the organization. Innovative strategies must be made explicit in order to facilitate an external assessment of the strategy as well as access to external sources of financing. Flexible innovative routines e.g. on-going innovations circles, which are based on revising continuously fluid methods, practices and procedures, as well as regular innovative activities through interdisciplinary teams are characteristics of an enterprise which has concentrated on its management of innovation in a holistic manner [KSDW06].

The establishment of a culture which tolerates mistakes being made and active involvement in shaping the innovation strategy of the stakeholders concerned at all staffing levels are equally as important. Beyond this, in addition to internal factors determining the ways processes run, the drivers of business innovative processes are particularly required to analyze environmental factors influencing innovation. The latter encompasses, e.g. understanding the innovative strategies of competitors, the involvement of the structural and cultural company environment as well as the use of networking and cooperative potentials.

Companies must see holistic innovation management as a cross-sectional task aiming to investigate and evaluate innovative developments within and outside of the company, to uncover implicit knowledge and to generate new knowledge through the creation and implementation of external innovations. Understanding innovations as a result from a complex interaction of human, organizational and technological factors is a key feature of company strategies striving for a permanent increase in innovative capability as well as aiming at sustainable economic growth and human resource management.

5.5 Fostering Social and Organizational Innovations

In view of the transition from the industrial to the knowledge and service society, social and organizational innovations are increasingly gaining in significance, while technological innovations are losing their innovation monopoly [HKS08]. Intangible, non-financial assets (e.g. individual skills, tacit knowledge, relational and human capital, intra-organizationally generated routines and procedures) essentially form the source of companies' sustainable capabilities to compete and face the future and play a significant role in line with a company strategy aimed to permanently induce innovations and which is based on a high degree of innovative capability [HTH10, SvdBH09].

The concept of social innovation encompasses all consciously generated reconfigurations of social practices, processes, structures or patterns of behavior which are aimed at delivering the satisfaction of needs or solution of problems in a better way than already established methods are enable to [HKS08]. Examples are ecoconscious behavior, overcoming of traditional role allocations between men and women or the opening of innovation processes (see Sect. 5.6). Organizational innovations refer on the other hand to structural or processual modifications which have an impact on company practice. Examples of organizational innovations are flexible project management, family-friendly working patterns, the conscious formation of diversity teams or self-organized team work.

Although current outcomes of studies [HS10] show what important influence especially organizational innovations have on productivity, innovative capability and economic growth as well as the probability of success of technological innovations, the importance of social and organizational developments has largely been ignored. This has resulted in considerable innovative potential not being recognized and utilized. For this reason, rethinking needs to take place, aimed particularly at the estimation of the decisive importance of social and organizational developments for the innovative capability of a company. Companies are required to initiate social and organizational innovation processes to support and sustain economic and also social capabilities to cope with future demands [Gil00].

Fostering social and organizational innovations plays a central role even as a basis or precondition for product innovations or inventions. Protagonists in company practice and innovative research must develop an understanding of the fact that technological progress is essentially made possible by social learning processes and that the latter are also absolutely crucial for technological innovative processe. Companies which consciously implement social and organizational innovations into their company strategy create scopes of action regarding the inducement of complex system innovations which do not just represent simple production-focused passing fads, but sustainably improve basic service provision processes, information and communication techniques or organizational work processes in ways (cf. ibid: 27 et seq.).

Identifying social and organizational innovative potentials is especially crucial for the surviving of SMEs, as their competitive and innovative capabilities particularly depends on the bundling of personnel and intangible innovative potentials. Resource limitations caused by size, such as capitalization, staff diversity or personnel development opportunities compel SMEs to adopt efficient innovative operations, covering the utilization of all potentials for innovation.

The integration and fostering of social and organizational innovations contributes in the medium and long term to a significant increase in innovative capability. Stakeholders and decision-makers in economy and politics need to recognize that modifying human patterns of behaving and thinking as well as changing organizational processes and working procedures conceal a powerful force for innovation. The key to a sustainable innovative capability lies in the insight that the highest asset of a company is its intangible innovative potential [fHE05].

5.6 Opening of Innovation Processes

Current social trends such as increasing digitalization, growing competitive pressure through globalization, the proceeding connection of knowledge, shortening of product life cycles and the associated pressure to innovate as well as the extension of customer focus all support a modified understanding of innovation, which is characterised by new relationship patterns between socio-economic stakeholders [GE06]. Companies increasingly tend to open up their innovation processes in order to integrate internal as well as external stakeholders in innovation projects from the very start.

Open innovation processes are characterized by the fact that they cross over the boundaries of departments and organizations. They contain three core processes: The *Outside-In-Process* describes the process of the integration of external knowledge into the innovative processes of the company. The creative potentials of customers, suppliers and partners are actively injected into the company and rendered useful for the quality of the innovation process [GE06]. In particular, lead users, that is to say, especially innovative consumers with extensive market knowledge and a feeling for future trends, are to be involved in the Outside-In-Process in generating new ideas, products and services [Hip86]. The *Inside-Out-Process* on the other hand covers the externalisation of internal knowledge, which can serve the company, e.g. by earning licensing fees for patents, which cannot be used for the actual operational activities of the company. Strategically valuable, unique resources of the company are thus regarded as the starting point for justifying competitive advantages [RP06].

A link between Outside-In and Inside-Out is represented by the *Coupled-Process* which connects the internalisation of external know-how with the externalisation of company-internal knowledge, so as to guarantee a balance between give and take [GE06]. Non utilized innovative potentials outside companies are released by the opening up of innovation processes. Factors such as cost pressure, lack of risk capital or company-internal human potential can thus be countered through this [RP05]. The integration of external actors in the value creation chain should be focused throughout the entire innovation process, from the generation of ideas to the later phases as well as product launch to ensure that, e.g. an added value to classical marketing is achieved.

The understanding of the role of the customer likewise underpins a basic shift from the consumer to the innovator. Customers are no longer just perceived as passive consumers of products and services, but are acknowledged as an active-creating part of the innovation process, through whom the previously predominant focus on the customer is extended by the aspect of customer integration. Decision-makers in companies are required to recognise innovation projects as an interactive process between company and market, so as to fully realise the innovative potential of external actors (cf. ibid).

In order to establish this new understanding of roles in the strategy and self-understanding of companies, a fundamental change needs to occur in the patterns of thought and behaviour among all the actors involved in the innovation process. Existing concepts also need to be defined anew. Potential innovators must acquire new, individual skills, especially in terms of soft skills and social competences. These include product competence in matters of detailed knowledge of products, services and market situations in order to recognise future needs and trends and increase motivation to take part in the innovation process. Technical competence is of equal importance, meaning that actors can be involved in the development of application-focused solutions with the aid of knowledge about technological requirements and possibilities. Beyond this, potential innovators need managerial and team competence in order to create the conditions for effective cooperative work in innovation networks to focus on the target setting of the innovation process as well as imbuing open innovation processes with the strong leadership and structure, which it requires in spite of its self-organising character [PI09].

Organizations are also faced with the challenge of designing operations and communication at the interface between company and customer in a strategic manner [PI09]. Open innovation networks and communication platforms, e.g. through web-based applications, innovation circles, open-source-communities or crowd-sourcing, have to be set up. In this connection toolkits for open innovation processes in order to access the implicit knowledge of stakeholders must be developed: endeavors by large companies such as Audi, Adidas or BMW are already bearing fruits, while other companies are even based exclusively on the concept of open innovation (e.g. MySQL, Skype SA, Zagat). Especially in the computer games industry, the use of principles such as open source is enjoying exceptionally great popularity and shows the immense possibilities of open innovation processes [RP05].

5.7 Continuous Competence Development

As part of the demographic change, employees will need to work longer and undertake a wide variety of tasks in the course of their professional life, which will require and encourage a process of a continuous and life-long development of skills and competences. In view of the growing economic dynamism and the unavoidable ageing of the workforce, companies are no longer just concerned with recruiting young, qualified and capable employees and then retaining these in the company, but with supporting a process of systematic and life-long learning and competence development for all employees [fHE06].

In this process, an ageing workforce presents both risks and opportunities for companies. The increasing departure of older employees can lead to a considerable loss of human potential, as years of knowledge gained from experience is lost, if companies do not retain this in time and pass it on to new employees. The question of knowledge protection due to the loss of aged employees thus becomes an urgent problem [Nag09]. Managers as well as employees need to be convinced they should no longer focus on the risks of an ageing workforce, but should particularly aim to make use of having a wider age differentiation available [Tik11].

The key issue in managing an age-diverse workforce is the transfer of know-that and know-how between the different generations. Practical knowledge gained from experience and specific skills of older employees can be implemented systematically and combined with the knowledge freshly acquired by next generation employees. In particular, e.g. teams with members from mixed generations, learning integrated within the working process and reflections on and the recording of knowledge gained from experience plays an important role in this context [Gmb08]. The mutual competence development of young and older employees within working processes thus becomes an important key to use synergy effects and increase the company's innovative capability.

The necessity of lifelong learning and the trend to dynamic professional biographies as a consequence of flexible job markets lead to a changed profile for individuals in terms of requirements and qualifications. Purely technical qualifications decline in importance, while key qualifications and general life skills acquire a growing importance for companies. Key qualifications such as the capacity for team work, communication skills, social and intercultural competences, creativity, resilience, personal learning competence etc. provide the necessary professional flexibility to remain capable of being over the whole working life [EK04, Opa08]. These changes in working requirements offer new opportunities for the (re)integration of staff with few qualifications, as many of them frequently have a large store of tacit skills.

Examples for tacit skills are a feeling for technical and organizational procedures, being aware of disturbances on the basis of diverse information such as noises or knowledge of informal practices which deviate from what is planned, but which are necessary and effective in achieving practical outcomes. Developing these skills and forms of knowledge can therefore offer new ways of promoting the targeted potential of those with few qualifications in view of the transformation of the knowledge society and the demographic developments [Bau09]. In the future, the question will thus be even more strongly one of involving all employees in lifelong learning processes and also consciously taking account of groups of persons such as those with few qualifications, those who have got out of the habit of learning and older employees [ZF06].

As the initiation and implementation of innovations is just rooted in the knowledge of decision-makers and specialists, high-quality learning experiences for all employees are very important to strengthen the innovative capability of a company.

A system of specific learning and competence development measures contributes significantly to the targeted promotion and use of human potentials for innovation, supports the individual for maintaining long-term employability and is a competitive advantage in the war for talents.

5.8 Integrative Design of Work and Learning Environments

The necessity of continuous learning and competence development in order to strengthen the innovative capability conflicts with the increasing time pressure of the economic and everyday life. To cope with this dilemma, organizations have to overcome the traditional separation of working and learning. Learning processes have to be systematically integrated in daily working routines and into the corporate culture:

> The accelerating rate of change in business forces everyone in every organization to make a choice: learn while you work or become obsolete. [Cro10]

Companies which still strictly separate their learning and working environments from each other are increasingly distancing themselves from modern forms of innovative organizational practice. Innovation work does not come about without effectively designed company-internal learning processes [ES01]. Measures of work-integrated learning make possible that employees learn at their workplace. At the same time they reduce the efforts of transfer that are connected with traditional and external forms of learning. Employees are enabled to develop their skills and qualifications with regard to the specific problems or situations they are dealing with in their work processes [BH09].

Work-integrated learning mediates necessary work-specific knowledge which the employees develop through handling of their everyday tasks. The learning venue is the workplace within the entrepreneurial context itself so that learning processes can be designed as an active and problem-solving perusal of authentic demands in real-life work and production processes [THJ11]. Companies have to ensure that those training forms corresponding to the contents of work are made attractive to their employees. This can, e.g. occur through ensuring the provision of adequate learning times, the compulsory implementation of further training in the company strategy, material preconditions for financing further training as well as generally convincing staff that they are suited to benefit from the qualifications and knowledge to be gained. In addition, variation in methods and media as well as a learner-centered perspective are significant factors, when it comes to prepare employees to develop their competences continuously within the working process.

Whereas formal learning opportunities decline in importance since it lacks flexibility, practical relevance and efficiency regarding time and money, focus should be directed to extending informal learning settings. Informal learning protects application-related knowledge and enables the actors to organize and control their learning themselves in terms of task-based skill development. Formal learning processes in every day working life cover, for example, quality circles, milestone meetings, forms of computer-based learning or blended learning as well as coaching, supervision and hospitation. Examples for informal learning processes in companies are internet researches, use of blogs, fora and wikis, collegial assistance, as well as taking on new work tasks, e.g. in the form of job rotation. Microtrainings are defined as short, interactive and flexible forms of work-integrated learning that support informal and non-formal learning processes at the same time. They are taking advantage of the different states of knowledge and expertise of employees to encourage active learning and transfer knowledge between people.

Work-integrated learning is learning of practice not learning about practice. In order to focus attention on these forms of practice-oriented learning, the recognition of informal qualifications and practical competences by management is essential. In addition, opportunities must be afforded for cooperation and communication between the actors in the working process and to develop autonomy and a sense of responsibility for learning processes in the company. Decision-makers are required to design work contents transparently as well as to guarantee a variety of demands within the work tasks to be accomplished. The requirement for employees to participate in design processes and the evaluation of learning opportunities is likewise an important factor in designing integrative work and learning environments.

5.9 Work-Life-Balance

The profound and dynamic changes in the working world are huge challenges for the mental stability and employability of people [Dah09]. The necessary flexibility of employees requires measures for establishing and continually maintaining the sensitive balance between working and private life in order to foster the productivity and innovativeness of every employee and thereby of the whole company. Work-Life Balance can accordingly be defined as a multi-dimensional driver of innovative capability, as a balance between working and private life brings success both for individuals and organizations. What is constantly involved in this, both from a positive as well as a negative perspective, is the strong connection between the different dimensions of life, which were originally viewed as contrary to each other [MN07]. The former borders between work and life become blurred which makes the establishment of a sustainable balance much more difficult.

In this context, companies are faced with the challenge of developing generation-specific and individually adapted concepts and measures for Work-Life-Balance [BMF08]. Organizational measures contain, e.g. work-time models to meet specific needs, an individually adapted work organization, concepts for flexibilizing the place of work, services to support a preventive healthcare and possibilities for child care during working hours [BMF08].

An example of a holistic Work-Life-Balance concept which provides support for employees in making professional and family life compatible was developed by the Deutsche Bahn AG primarily in form of specific work-time concepts and possibilities of teleworking. A further family-friendly measure to support the Work-Life Balance includes the cooperation with “Familienservice”, an agency operating across the country which is specialized in passing on offers of care. Furthermore, the call center of the DB in Duisburg has a company kindergarten at its disposal, whose offers are very gladly taken up by the employees [BMF08].

The targeted implementation of measures for securing Work-Life Balance leads to an increase in work place satisfaction and motivation as well as to higher productivity and innovativeness. Such measures need to be seen as a decisive competitive factor, as losses in the area of qualified specialists can be avoided and the recruitment of personnel is facilitated through the enhanced attractiveness of the company [BMF05b, FS03]. Potentials for reducing costs also result from the reduction in re-procurement or fluctuation costs, transition costs, re-integration costs and the costs incurred through absenteeism [BMF05a].

It can be recorded that a Work-Life-Balance maintains a sustainable productivity and innovativeness of the employees and therefore increases the innovative capability of a company. The establishment of this balance is primarily based on the structural circumstances in the working and private environment in combination with individual and mental factors like state of health, stress level and resilience [MN07].

5.10 Innovative Forms of Work Organization

As a decisive answer to the increasing flexibilization pressure a profound transformation of the organization of work is permanently discussed amongst employees, managers and political decision-makers [Tot04]. The dynamism of individual occupational biographies, mobility, flexibility, but also the balance of family and working lives are aspects of this challenge. To enable people to remain healthy, employable and motivated in this new environment, comprehensive modifications are required in terms of individual and organizational forms of work, which are no longer simply focused on paradigms of cost reduction and lean process designs, but on the efficient utilization and enhancement of human resources [fHE07].

The globalized, dynamic economy of today and constant fluctuations in the demand for goods and services lead to an increasing pressure to be more flexible in terms of transferable skills and adaptable forms of working. Strategies designed to enhance flexibility, such as flexible working times, part-time employment and temporary work, are used in business practice to enable companies to adjust the volume of their workforce to the variations in demand [fHE06]. Employees consequently have to learn to cope with flexible employment relationships, encompassing more working times at weekends, during the year and according to individual choice. Individually adapted strategies for providing flexibility in this process certainly present advantages for employees, e.g. when working time regulations enable them to fulfill private and family commitments comprehensively [Tot04].

The question how the individual and organizational need for stability can be met under the increasing flexibilization pressure and the increasing acceleration of working processes can be answered with High-Road approaches to work organization [ET07]. Whilst older Low-Road approaches focus on retaining competitiveness mainly through reducing short-term costs, High-Road approaches aim to place a company in the position of being continuously innovative and competitive. This can be achieved by encouraging the engagement of employees in such a way that it improves the quality of work and at the same time leads to a fulfilling and healthier work in the long run [fHE07]. Modern High Road approaches are consequently aimed at being sustainable and promise to provide a balance between quality of work and productivity as well as between stability and flexibility [KO07].

An example of the successful introduction of innovative forms of organizing work is provided by the Volkswagen Group. The company developed the concept of the "Breathing Company": the various forms of breathing that are available for employees encompass flexibility in terms of hours, shifts and working days per week. Besides the concept of the "Breathing Company", however, there are further examples of innovative work organization within the Volkswagen Group like the continuous improvement process, creative occupational concepts and a dynamic remuneration system [fHE06].

A healthy balance between operational flexibility and personal stability can be achieved through a modernization of the organization of work. The increasing pressure to be flexible is, however, accompanied by a loss of stability and security for employees and companies despite the advantages of new models of working in terms of time and organization. Against the background of the increasing need to be flexible and the acceleration of processes, dangers of imbalance arise, especially if the measures to bring about flexibility are implemented unilaterally for (economic) company purposes. A company culture which is adverse to innovation, the creation of dog-eat-dog attitudes but also an overexpansion of the limit of performance and the health impairments associated with this have to be taken into consideration as possible consequences of an imbalanced and excessive flexibilization.

5.11 Management of Uncertainty

The dynamic developments and changes in the economic world bring along that company´s top management has to deal more and more with aspects of uncertainty. Even technical production processes have frequently come to be characterized by uncertainties and outcomes which cannot be anticipated. The permanent lack of certainty about the future leads to companies equipping themselves with corresponding strategies for potential, unexpected developments and having to adapt organizational principles as well as processes. Coping with what cannot be planned for, i.e. dealing with situations and demands which cannot be foreseen in advance is a task for management and for every employee [Sch05, Böh05]. These challenges can only be met by the interaction of organizational and personal development.

Managing uncertainty is becoming a core skill, as it enables people and companies to promote innovations under flexible and dynamic conditions. Especially innovative processes require a high willingness to accept risk and confidence in dealing with events that cannot be planned or foreseen: Dealing with innovation is always dealing with uncertainty [Now08]. Traditional approaches in innovation management that are oriented on a precise planning and controlling of innovation processes run into danger to hinder innovations rather than promoting them [Böh11]. Against this background, a paradigm shift in managing uncertainty is required: from the reductionist approach to master and eliminate uncertainty to the systemic approach to efficiently cope with uncertainty. What cannot be planned for must become the norm, not by seeing it as something to be repressed, but as something to be confronted head-on [BPS04].

Effective strategies for overcoming uncertainty derive from subjective practical knowledge and other implicit knowledge. Practical knowledge is gained through individual experiences and practical action and is therefore linked to persons and situations [Böh05]. The continuous development of this kind of knowledge can only be acquired through learning within the working process, as it ensures to be up to date and specifically connected with the practical working tasks [EPB06]. A completely rational acting that is oriented at controlling and planning is consequently not sufficient for managing the unplanable. Instead, subjective and experience-led forms of acting are required. The necessary skills and competences can only be developed through learning processes that are oriented to practical acting [BPS04]. The aim of these learning processes is the systematic-methodological linking of generalized technical knowledge with the ability to relate general knowledge to concrete circumstances in practice and to supplement this with the knowledge gained from experience required for this [Böh05]. The step to manage uncertainty without eliminating its innovative power is a step to establish a system of continuous innovation.

6 Outlook

Innovation is a key factor for competitiveness on today's dynamic global markets. In order to safeguard this competitiveness in the long run organizations have to show a high degree of innovative capability in order to permanently – not just punctually – induce innovations. As innovations, understood in a holistic manner, emerge from the complex interrelations between human, organizational and technological preconditions of an enterprise, a sustainable innovation management starts out in designing these very preconditions in order to finally establish a system of continuous innovation. Against the background of central dilemmas of economic acting in modern working environments, the research and development project "International Monitoring" (IMO) has identified eleven core strategies to strengthen the innovative capability and thus the competitiveness of organizations.

The identified strategies aim at creating overall innovation-friendly framework conditions that support the establishment of a system of continuous innovation. They foster the emergent character of innovation and take account of the fact that innovative employees need an environment that facilitates creativity and learning processes and which is characterized among others by cooperation, openness, trust and error tolerance. Attention has to be paid to the fact that the strategies have complex reciprocal effects and have to be implemented individually or in combination according to the specific internal and external situation of an enterprise, so that they primarily serve as a type of orientation aid and navigation map especially for SMEs. To deduce concrete measures for organizations it is necessary to diagnose the individual situation of the specific enterprise and consequently to react to identified deficits.

During the further course of the IMO-Project relevant and concrete design features of the strategies will be identified. The features offer both an orientation matrix for decision-makers and implicate practicable approaches for the realization of concrete measures to strengthen the innovative capability. Furthermore, a web-based strategy planner is under construction that offers a self-serviceable individualized diagnosis of the innovative capability of SMEs and additionally gives concrete recommendations for action regarding the implementation of certain strategies and design characteristics.

Against this background the following questions are of particular interest for further research on strategies that increase the innovative capability of companies:

- Which configuration features and change activities constitute the strategies?
- How can SMEs use these strategies to generate and develop framework conditions that establish a system of continuous innovation.
- What are decisive interdependencies between the strategies?

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Innovative Capability – An Introduction to this Volume

Sven Trantow, Frank Hees, Sabina Jeschke

Abstract The capability to innovate in an on-going manner is emerging as a decisive key factor in today's complex and dynamic world of business and work – the ability to stay competitive is becoming identical with the ability to innovate. As an introduction to the collection of essays, this contribution discusses both the origins as well as the characteristics of innovation and provides an underlying definition of innovative capability. Building on this, key challenges for business operations are outlined, which must be overcome, if innovative capability is to be enhanced on a sustainable basis.

Key words: Innovative Capability, Innovation, Innovative Capacity, Organizations, Formation of Innovations

1 Innovative Capability and the Genesis of Innovation

"The only constant is change". After 2500 years Heraclitus' insight seems to be more relevant than it ever was. The economic world of today is enticing, with its high, perhaps even excessive, levels of dynamic and complexity. The huge economic growth in threshold countries, uncontrolled technological progress and unprecedented global networking are all leading to serious fluctuations in entire market areas and national economies, to a shorter planning time and an economic framework which is growing ever more complex. Just how such confusion arising from complexity can result in human powerlessness was forcefully demonstrated by the global financial crisis [fin]. The free fall and comet-like resurgence of the global automotive industry is striking evidence for how incredibly dynamic, volatile and unpredictable markets and corporate environments have become [WKT+11].

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How then can decision-makers in economics, politics and science deal with these conditions? How can we retain our capacity to act effectively without ourselves becoming the puppets of a system whose internal dynamic has long since outgrown our capacity of rational cognition [Hen92]?

In this turbulent environment, innovation is the new old magic formula to survive, act and compete efficiently in the long run [Sch34]. By now the term comprises much more than just new products or technological developments. Innovation rather suggests "being the new, state-of-the-art navigation map that offers orientation on the uncertain journey into a fragile future" [Now08]. Therein lays the hope of a self-confidential and responsible handling of a future that cannot be planned and is constantly changing. Innovation thus rises to become the actual essence of economic success. On a practical business level, this fundamental elevation of its significance leads to a kind of innovation pressure [RS10] – anyone who is not innovative enough will fall by the wayside!

But what constitutes an innovative company? Or, to be more precise: what is it that enables a company to continuously induce innovations? One thing is sure: they do not arise out of nothing. Product and service innovations, for example, are frequently based on existing products or services (incremental innovations): Microsoft Windows 8 is a successor to Windows 7, and the German E-Postbrief is a hybrid letter which combines the security of a conventional letter with the speed of a digital e-mail. What comes next is the result of what has gone before – is that really all there is to it? Could Windows 8 exist without the host of excellent software developers who work for Microsoft? Would the E-Postbrief stand a chance of success if the Deutsche Post AG did not already have recourse to an extensive infrastructure for logistics and postal services? So, beside technology human and organizational influences play a decisive role in the genesis of innovations. This connection still becomes clearer in the case of radical innovations. The World Wide Web would definitely not have been invented at CERN if the serious problems they were having with chaotic information flows [Ber89] had not coincided with the structured brilliance of Tim Berners-Lee. The most far-reaching innovation of the 20th century arose from the intertwining threads of these special intra-organizational circumstances and problems at CERN, the exceptional talents of Tim Berners-Lee and the technological development of hypertext – limiting the genesis of this fundamental innovation down to one of these dimensions would effectively be an error of reductionism, and obscure the actual nature of how innovations come about. They are neither merely the results of processes of technological development or improvement nor are they simply the realization of creative ideas. But by taking a holistic view of innovations and considering the many facets of their origin and kind we can see them as emergences of the entire socio-technological system which induces them.

So when we ask what enables companies to induce innovations, we are actually enquiring about the complex interaction between human, organization and technology [HHL09]. Every innovation is always the result of a complex interweaving of these three dimensions and the interdependent processes which emerge from them. The idea that it is possible to monitor these processes precisely in a company or even control them at all is a widespread misconception. And it is the same modern misconception which attempts to persuade us that innovations can be planned and controlled [Now08, SBB+06], that they could be initiated, implemented and controlled, but only with the right kind of management. Of course, management – of whatever kind – can be a part of the innovative process. But innovations are not created on the drawing board, nor by working through check lists or phase models. Innovations emerge from the complex thinking, acting and interacting of people going about their everyday work under certain framework conditions. In the context of the modern industrial nations' transition to knowledge- and service-based societies and the associated "paradigm shift in the innovation system" ([Bul06]; translated by author) it is particularly important that the traditional technology- and product-oriented perspective on innovation develops into a holistic view which acknowledges the key role of people and their working conditions in the concept of innovation [Sch07, how].

A holistic understanding of innovation, therefore, takes into account more than simply the management of the processes of product or technological development. It does not even begin with the generation of ideas, but poses the far more fundamental question of what conditions need to be created for a system to continuously – not just intermittently – induce innovations. These are the conditions which constitute innovative capability, which can relate to individuals, companies, networks and teams and to whole societies[1] as a multidimensional construct with many levels [HTH10]. Against the background of today's complex dynamic world of business and work, it has risen to become one of the most important success factors in safeguarding the competitiveness of companies and entire national economies [DEKS06]: The ability to succeed in the market-place in the long run is more and more based on the ability to innovate. Summing up one can record that:

- Organizations need to induce innovations, to remain long-term competitive in a turbulent market environment.
- Seen in the context of a holistic understanding, innovations are emergences from socio-technological systems, and as such cannot completely be planned, steered or controlled.
- The innovative capability of companies comprises the complex interrelationships between the human, organizational and technological requirements to continuously induce innovations.

2 Not Everything is Innovation

In order to identify the conditions required to produce innovations on a continual basis and thus be able to refine our concept of innovative capability, we first need to specify the fundamental characteristics of innovations. Therefore the question is:

[1] Thus, for example, international benchmarking systems such as the German Innovation Indicator (http://www.innovationsindikator.de) or the Innovation Union Scoreboard

what exactly is actually to be induced? What is an innovation? Remarkable though it may seem, the term innovation has the particular quality of describing a generally recognized key success factor in today's economic and working environment, without ultimately clarifying what it refers to. Innovation has long been one of a large stock of management buzz words, stylized into a kind of savior-figure [Pae03] with the power to generate growth, create jobs, tackle crises and promote prosperity in society. The ubiquity of the word and its inflationary use [kru] are leading to an over-expansion of its meaning. As the term is watered down it is still unclear whether the term innovation is merely loaded with optimism or whether it really possesses the desired power to change something:

> It only seems appropriate that, in times of economic challenge, global competition, and an overabundance of similar products and services, leaders would turn to innovation as the new corporate mantra. Unfortunately, the concept of innovation has been so widely used and misused that many people are now confused as to what it really is. [Dun02]

The first thing we need is a criterion by which to differentiate between innovation and non-innovation. It has been clear since Schumpeter that new ideas, products or technological discoveries alone do not constitute innovation. For him, innovation had to have the power to effect a far-reaching change with regard to economic development – for example, the transition from the mail coach to the railway. Market application and the commercial success that comes with it are therefore frequently used as essential criteria [Wit10]. However, as we depart from a product- and technology-centered perspective and establish a holistic concept of innovation, these criteria are also far from definite. Social innovations, for example, [HJ10] in other words fundamental changes to our patterns of behavior, are not designed to be put on the market at all, and any financial profit can only be estimated very roughly, if at all. Organizational innovations, such as the introduction of safety at work regulations or the establishment of environmental standards, often focus more on increasing social or environmental sustainability than on economic success – although that can also turn out to be very appreciable [San05, Ram09].

It makes sense, then, to look beyond purely economic factors in our assessment of the consequences of innovations. Bullinger and Schlick therefore define innovation as "problem solution which uses a new approach to produce a profit. [...] It comprises the entire process from the idea via development and production through to market launch or realization" ([BS02]; translated by author). The criterion of economic success can thus be replaced by the more general idea of profit, and the launch of a product on the market by the realization of a new approach or a new idea. Here, though, both the profit and the realization must incorporate an additional time dimension. A purely short term profit or the implementation of an idea on only a temporary basis would not have the power to cause an economic, social, or environmental change which is necessary to be considered as an innovation – a new business model which is introduced but cannot establish itself on the market is no more an innovation than a quality management system which only raises the quality of a product in the first two weeks. The time component emphasizes the central characteristic of the uncertainty and unpredictability of innovations – whether something is an innovation or not can never be determined a priori, but only in retrospect. If we extend the notion of profit beyond the economic dimension, and include social and environmental aspects, and then add the criteria of the power to effect change, we can describe a holistic concept of innovation as follows:

- Innovation is the realization of new ideas that contribute to sustainable[2] changes.
- The innovative capability of companies comprises the complex interrelationships between the human, organizational and technological requirements to continuously induce and realize new ideas that contribute to sustainable changes.

3 Dilemmas of the Modern Working Environment

In 2007 the German ministry of education and research initiated a research and development program entitled "Working – Learning – Developing skills. Potential for Innovation in a Modern Working Environment" ("Arbeiten – Lernen – Kompetenzen entwickeln. Innovationsfähigkeit in einer modernen Arbeitswelt", or A-L-K for short) [BMB07]. In a transdisciplinary approach to research, the program, which currently comprises more than 100 joint projects, enables companies and employees to identify and successfully implement conditions, which foster innovations. The program is based on the sustainability-oriented concept of innovation which includes, besides the economic success, the social progress as a criterion for innovation [BMB07]. This recognition of the one-sidedness of purely economic criteria for assessment – and therefore criteria which are usually strictly based on figures – is gaining wider acceptance in the contexts of academic and economic policy. The idea that economic and social benefits are considered as well, in other words the basic principle of the social market economy [MA76], gets more and more important.[3]

On the other hand, these attempts at a more integrative approach are confronted with the harsh realities of a financial capitalistic world economy. In the day-to-day competition of global business neither social nor environmental benefit will ultimately decide a company's future – the only critical factor is economic success. In this context it is inevitable that stakeholders in the world of business focus primarily on the economic profits. Additionally, the dynamics and complexity of today's global markets reduce the time given for planning to such an extent that it is not always possible to focus on a long term action strategy. On the one hand, economic pressure forces companies and their employees to realize profits as swiftly as possible. On the other hand, economic and environmental conditions are changing so rapidly that it is no longer possible rationally to assess the longer-term side effects,

[2] Sustainability is meant here in the context of the three-column model, which adds a social and an economic column to the original environment-related concept [enq] (cf. [Bra00], 75).

[3] Correspondingly the European growth strategy is founded upon the notion of smart, sustainable and inclusive growth [eur].

long-distance effects and repercussions of any given activity. The upshot of this fundamental uncertainty is that economic activity is focused on maximizing short-term and usually monetary profits.

As part of the German A-L-K program, the "International Monitoring"[4] research and development project (IMO) has identified this area of tension between sustainability and short-term profit maximization as the meta-dilemma of the modern working environment, and therefore as a paradigmatic challenge for activity conducive to innovation. Squaring the circle of economic activity rests on the impossibility of reconciling the doctrine of the homo oeconomicus with attempts to achieve sustainability. The underlying economic maxim of rapidly realizing the greatest possible profit is pressing economic actors to behave in a unilaterally monetarist and reckless way which is incompatible with a far-sighted, responsible and long-term successful management [Thi09]. One may ask, whether the neoliberal subordination of social responsibility[5] in the long run primarily leads to its dissolution.

The reasons why economic actors often focus on the short-term maximization of profit despite the widespread efforts to achieve sustainability can be described with reference to four dimensions of economic pressure:

- Cost pressure
- Pressure to succeed
- Time pressure
- Flexibilization pressure.

The IMO project has contrasted these dimensions with four basic conditions for socially and economically sustainable organizations that are highly capable to innovate [HTH10]. The result is four interdependent dilemmas which can be seen as elementary problems inherent in economic activity in general and in reinforcing innovative capability in particular (cf. Fig. 1)[6]:

- *Responsible use of human resources vs. cost pressure* describes the requirements of a comprehensive, anticipatory and responsible management of personal knowledge potentials, skills and competences under the simultaneous economic pressure to cut costs.
- *Long-term strategies to increase innovative capability vs. pressure to succeed* describes the increasing pressure on companies to make fundamental changes to structures and processes in order to strengthen their innovative capability whilst being required to quickly achieve objectively measurable success.

[4] The IMO project is being run by the institute cluster IMA/ZLW & IfU of the RWTH Aachen University. The overall aim of the joint project is to establish ongoing International Monitoring (IMO) and the action areas associated with it, on the topic of innovative capability, to support development of the content of the BMBF F&E program "Working – Learning – Skills. Potential for Innovation in a Modern Working Environment" (ALK), as well as contributing to increasing the sustainable competitiveness of Germany and Europe in the global context.

[5] "The social responsibility of business is to increase its profits" [Fri70].

[6] Beyond that, the dilemmas also provide a framework of reference which helps the IMO project to structure inter- and transdisciplinary knowledge on the topic of innovative capability and give it a common context [TSHJ10].

Fig. 1 Dilemmas of economic acting in the modern working environment

- *Time for learning processes vs. time pressure* describes the individual, organizational and social necessity for learning and development processes under conditions of increasing time constraints on work.
- *Need for stability vs. flexibilization pressure* describes the demand of individuals, organizations, networks and societies for safety of current and planning of future processes under the increasing socio-economic pressure of permanent transition and the associated handling of uncertainty and change.

These dilemmas therefore illustrate the principle challenges economic actors in today's working environment need to manage. Their main characteristic feature is that they cannot be resolved or eliminated. The four dimensions of economic pressure are constitutive components of every market economy – including the social market economy. They are characteristic of healthy and productive competition and as such are the engine which drives economic performance and dynamism. The real challenge is to find appropriate strategies for economic actions to make it possible to deal efficiently with the dilemmas – in other words to manage them – and thus to increase the innovative and competitive capability of companies in a sustainable way.[7]

4 Structure of the Book

This originated from the research and development project "International Monitoring". The contributions from German and international experts outline the the topic of innovative capability from a practice-oriented angle, and offer a glimpse behind the scenes of innovations. The central issue is not the description of features of successful innovation processes or how innovations can be efficiently controlled and managed, but under which conditions they can emerge in the first place. In what way can individuals, organizations, networks and societies be enabled to continuously induce innovations?

Experts from thirteen different countries wrote 25 articles in total and 20 commentaries that give us an international and transdisciplinary insight from multiple perspectives into areas of theoretical research and practical activity concerned with innovative capability. With an emphasis on operational practice and the derivation of political recommendations these pieces will be of equal interest to people involved in academic research, economics or politics who want to discover more about the prerequisites for innovations, and the conditions conducive to their emergence. The texts in this collection are sorted by topics into four main chapters[8] which consider innovative capability from a variety of perspectives. In conclusion, they are supplemented in a fifth chapter, outlining some of the key outcomes of the German research and development project "Working – Learning – Developing Skills. Potential for Innovation in a Modern Working Environment".

4.1 Management of Uncertainty – Key to Innovation

Uncertainty is a central and a constitutive feature of innovation. With reference to the dilemma *need for stability vs. flexibilization pressure*, it is clear that a way of dealing with uncertainty has to be found which makes it possible to act with confidence whilst allowing plenty of scope for managing the unpredictable. However, the traditional, production-based desire to control and eliminate uncertainty implies a risk of jeopardizing innovations instead of promoting them. In his intro-

[7] The IMO project has identified eleven basic corporate strategies for overcoming the dilemmas [THRJ11]

[8] The titles of these main chapters correspond to the IMO project's four fields of action, in which German academic and economic experts developed the fundamental thematic principles behind innovative capability, created an up-to-date knowledge base and looked at trends for the future. There are 19 reports from the experts in all, and they can be found online at: http://www.internationalmonitoring.com/en/downloads/project_research.html.

ductory piece, *Fritz Böhle* therefore argues for a new, productive way of dealing with uncertainty which aims to cope with uncertainty rather than eliminate it. *Harald Wolf* builds up on this systematic analysis with a discussion on alternative management approaches aiming at maintaining the necessary balancing act between risk management based on security and a tolerance of uncertainty based on confidence and self-organization. Based on the fact that work processes becoming increasingly project-oriented, *Sibylle Peters* demonstrates how even the traditional forms of project management need to be supplemented with new, social approaches which are oriented towards the participants, in order to deal effectively with uncertainty and in a way which is conducive to innovations. The need to strengthen actor- and action-orientation to deal with uncertainty implies is a new way of looking at education and learning. *Johannes Sauer* argues for the expansion of the narrow, institution-bound concept of education into a comprehensive understanding of continued and lifelong learning which focuses especially on learning processes which are integrated in the workplace, and are informal and skills-based. *Martin Elbe* tackles the issue of how individuals can deal with the uncertain situation that normal employments provide security but now are an outdated model on today's more flexible job markets.

4.2 Developing Skills, Work Systems, Work Processes – an Innovative Challenge

The second chapter delves more deeply into the question of designing work and learning to be conducive to innovation. The dilemma *time for learning processes vs. time pressure* here implies that the increasing need for continuing further development on an individual and organizational level can only be met with if learning and working is fully integrated. In their introductory article, *Ernst Hartmann* and *Francesco Garibaldo* outline a conceptual framework for learning-oriented work systems. Against the background of what is already known about the features of jobs comprising intensive learning, they focus on the question of how these actually exist in everyday business and how they can be set up. The increasing link-up of working and learning processes is turning informal, unguided learning into a key driving force behind innovative capability. *Sibylle Peters* and *Yvonne Salazar* investigate the new group of protagonists who, independent of any traditional or professional staff development, are taking on more and more key roles in work-integrated learning activities. The opportunities for recognition and accreditation of these kinds of learning activities, and approaches for strengthening cooperation between universities and companies, are dealt with in the contribution by *Barbara Light* and *Ernst Hartmann*. The two contributions which conclude the chapter extend the focus beyond the integration of work and learning. *Peter Totterdill* shows that innovative capability in a knowledge-based economy is dependent on forms of organization of work which go beyond the traditional measures of economy of scale and guarantee simultaneous increases in productivity and quality of work ("high road" approaches). The chapter concludes with a contribution from *Francesco Garibaldo*, who analyses the challenges of establishing business conditions conducive to innovation against the background of the restructuring processes currently taking place in industry.

4.3 Innovative Capability and Change of Work

The massive upheavals in the modern working environment and the transition from an industrial society to a knowledge- and service-based one imply a paradigmatic change in our concept of innovation – people and work processes are rising to become key driving forces behind, and even the actual objects of innovations. *Jürgen Howaldt* and *Michael Schwarz* analyze this paradigm shift and offer insights into the particular characteristics and potentials of social innovations. Starting with the theory that creative people are the source of all innovations, *Matthias Trier* examines the personal living conditions which can increase the individual's innovative capability. Current processes of change in the modern working environment are being clearly defined by demographic change. This is the context for *Tarja Tikkanen's* discussion of the key challenges and especially the opportunities of an ageing workforce. The article by *Frank Emspak* departs from the realm of the individual and looks at the interrelationship between work and innovation as he discusses the socio-economic conditions needed to establish a system of continuous innovation. *Claudia Jooß et al.* create a link to research, and reveal how social innovative capability can be reinforced through interdisciplinary research networks.

4.4 Intellectual Capital – Human Potential as Innovative and Competitive Advantage

The increasing importance to innovative capability and competitiveness contributed by people, their knowledge and skills is reflected in the notion of intellectual capital. Human potential is even by management no longer seen as a cost factor but as a key company asset. However, the dilemma *responsible use of human resources vs. cost pressure* points to the fact that this new sense of value in corporate practice is still at odds with the pressure to reduce expenditure. *Peter Pawlowsky* opens the chapter with a comprehensive look at current developments in the area of intangible assets and intellectual capital. One important aspect here is how we evaluate intangible assets, which are as necessary in business as they are controversial. *Sabine Bischoff* and *Gergana Valdova* outline approaches to measure intellectual capital and use the open invitation concept to demonstrate the connections to innovative capability. Looking at typical conflicts of interest and dilemmas of practical company management, *Hans-Georg Schnauffer* reveals effective approaches to deal with knowledge and intellectual capital. *Bodo von der Heiden et al.* discuss the potential of serious games as playful learning and knowledge tools in companies. On a societal level and based on the lack of sustainable forms of dialogue and communication *Gün-*

ter Szogs examines the concept of the future center and related approaches to the transdisciplinary initiation of processes of innovation.

4.5 Findings from the German R&D Program "Working – Learning – Developing Skills. Potential for Innovation in a Modern Working Environment"

"Working – Learning – Developing Skills. Potential for Innovation in a Modern Working Environment" (A-L-K) is a German R&D program initiated by the German ministry of education and research, which currently comprises four thematic funding priorities and more than 100 joint projects which help companies and employees to create and organize working conditions conducive to innovation. The main areas of focus are:

1. Occupational safety and health
2. Innovation strategies beyond traditional management
3. Balance between flexibility and stability
4. Capacity for innovation in the demographic change.[9]

Provisional results from the first three funding priorities are already available, and they are outlined in this chapter. First, *Max Haarich et al.* introduce the nature of the A-L-K program's content and structure. I*ngo Leisten*, *Ursula Bach* and *Frank Hees* show that measures for a occupational safety and health form an important and multi-dimensional feature of innovative capability in a modern working environment. *Heike Jacobsen*, *Arno Georg* and *Milena Jostmeier* outline some new organizational strategies for innovation which differ from traditional management in being non-linear, crossing organizational boundaries and through subjectification. Taking the funding priority 'Balance between flexibility and stability' on focus, *Uta Renken* and *Angelika Bullinger* report on the use of social software to create effective networks of knowledge and participants in research.

The contributions in this anthology make it clear that a continuous generation of innovations cannot be ordered top-down, but depends on certain framework conditions that enable people to think, act and interact in an innovative way. They give answers to the question where there are possibilities to fine-tune and strengthen individual, organizational and social innovative capability, under which circumstances people develop new ideas and implement them in a sustainable way and what enterprises can do under today's working circumstances and economic environment to support them. The following articles and comments reflect the current state of insights on the topical area of innovative capability and derive basic recommendations on how science, economy and politics can contribute to a sustainable strengthening of innovative capability and competitiveness.

[9] "Capacity for innovation in the demographic change" is the most recent funding priority, and was only begun in July 2010. The first results are expected at the end of 2011.

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Spannungsfelder der Innovationsfähigkeit. Internationales Monitoring im BMBF-Forschungs- und Entwicklungsprogramm A-L-K

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Zusammenfassung Das vom Bundesministerium für Bildung und Forschung sowie vom Europäischen Sozialfonds geförderte Forschungs- und Entwicklungsprogramm „Arbeiten – Lernen – Kompetenzen entwickeln. Innovationsfähigkeit in einer modernen Arbeitswelt" zielt auf die Stärkung der Innovationsfähigkeit in Deutschland. Der Beitrag erläutert die Funktionen des programmbegleitenden internationalen Monitorings (IMO) und stellt zentrale Ergebnisse der bisherigen Monitoringaktivitäten vor. Dabei liegt der Fokus auf der Beschreibung von fünf elementaren Dilemmata des wirtschaftlichen Handelns in der modernen Arbeitswelt sowie deren Implikationen für den Bereich des präventiven Arbeits- und Gesundheitsschutzes.

Schlüsselwörter: Monitoring, Innovationsfähigkeit, Dilemmata, Querschnittsforschung

1 Einleitung

Innovationen gelten in den modernen Wissens- und Dienstleistungsgesellschaften als Schlüsselfaktoren für den wirtschaftlichen Erfolg und die Wettbewerbsfähigkeit von Unternehmen. Dabei versperrt die traditionell technizistische und produktorientierte Sicht auf Innovationen den Blick für den Menschen und dessen Arbeitsbedingungen als entscheidende Voraussetzungen zur Hervorbringung von Innovationen. Die organisationale *Fähigkeit*, innovativ zu sein, hängt häufig weniger vom technischen Entwicklungsstand eines Unternehmens als vielmehr von seinen Humanpotentialen sowie seinen internen Prozessen und Strukturen ab. In diesem Sinne ist ein neues, ganzheitliches Verständnis notwendig, das den technischen Innovationsbegriff um eine soziale und organisationale Bedeutungsdimension erweitert.

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Das BMBF betrachtet Innovations*fähigkeit* daher als Schlüsselqualifikation für wirtschaftlichen Erfolg. Letztlich sind es die Menschen sowie ihre Arbeits- und Lebensbedingungen, die Unternehmen dazu befähigen, Innovationen hervorzubringen. Das Forschungs- und Entwicklungsprogramm „Arbeiten – Lernen – Kompetenzen entwickeln. Innovationsfähigkeit in einer modernen Arbeitswelt" (A-L-K) sieht daher in kompetenten Menschen und wandlungsfähigen Unternehmen entscheidende Voraussetzungen für Innovationsfähigkeit (BMBF 2008: 7). Neben dem Förderschwerpunkt „Präventiver Arbeits- und Gesundheitsschutz" (P-A-G-S) fördert das BMBF aktuell die beiden Schwerpunkte „Innovationsstrategien jenseits traditionellen Managements" sowie „Balance von Flexibilität und Stabilität" unter dem Dach des Programms A-L-K. Damit umfasst A-L-K derzeit insgesamt 106 Forschungsprojekte, die in verschiedenen thematischen Bereichen dazu beitragen, Deutschland im Sinne der High-Tech-Strategie im globalen Wettbewerb zu stärken. Um die heterogenen Forschungsprojekte zu vernetzen, die mannigfaltigen Ergebnisse zu bündeln und auf diese Weise Synergieeffekte zwischen den Einzelprojekten hervorzurufen, werden thematisch verwandte Einzelprojekte zu Fokusgruppen zusammengeführt. Die Organisation des projektübergreifenden Austausches und Transfers übernehmen Metaprojekte, wie im Falle des Präventiven Arbeits- und Gesundheitsschutzes das Metaprojekt StArG. Zur weiteren Verbesserung des Wissensmanagements und -transfers nutzt das Programm das Projekt Internationales Monitoring (IMO), das sowohl programmintern die Ergebnisse der Förderschwerpunkte verdichtet und aufbereitet als auch im Kontext internationaler Forschung spiegelt. Die folgenden Abschnitte beschreiben, welche Rolle Monitoringprozesse in Forschungs- und Entwicklungsprogrammen und speziell im Programm A-L-K spielen. Anschließend werden erste Ergebnisse aus IMO vorgestellt und ihre Zusammenhänge zum Arbeits- und Gesundheitsschutz aufgezeigt.

2 Die Bedeutung von Monitoring-Prozessen im Rahmen des Forschungs- und Entwicklungsprogramms A-L-K

Monitoring kann kurz gefasst als systematische Untersuchung bezeichnet werden, die sich durch wiederholte Beobachtungen über die Zeit auszeichnet [RLF04]. Sie ist meist zielgerichtet und themenorientiert. Der aktuelle Wissensstand zu einem bestimmten Sachverhalt, einem Forschungsgebiet oder einem gesellschaftlichen Diskurs wird in einem geographisch und/oder thematisch festgelegten Gebiet analysiert. So untersucht das IMO-Projekt das Themenfeld Innovationsfähigkeit für den Wirtschaftsstandort Deutschland und unter Berücksichtigung internationaler Expertise.

Da auch innerhalb eines Themengebiets nicht sämtliche Informationen berücksichtigt werden können, entsteht die Notwendigkeit zur Selektion. Diese kann z. B. durch eine Festlegung auf relevante und repräsentative Akteure (Unternehmen, Branchen, Forschungsinstitute, Marktforschungseinrichtungen etc.) erfolgen. Das IMO-Projekt orientiert sich dabei an einer interdisziplinären Community nationaler und internationaler Experten aus Wissenschaft und Praxis. So arbeiten im nationalen Expertenarbeitskreis derzeit knapp 50 Mitglieder in vier thematisch differenzierten Aktionsfeldern. In einem International Panel hat das IMO-Projekt ca. 20 internationale Experten zum Thema Innovationsfähigkeit zusammengeführt.

Im Gegensatz zur Evaluation wird beim Monitoring das Wissen über den Untersuchungsgegenstand prinzipiell prozessual generiert und befindet sich in einem ständigen Wandel. Am Ende des Monitoringprozesses muss deutlich erkennbar sein, wie sich der Untersuchungsgegenstand über die Zeit verändert hat. Anhand dieser Ergebnisse sollte darüber hinaus eine Prognose über zukünftige Entwicklungen möglich sein. Im Rahmen des Monitorings von Forschungsprogrammen lässt sich zwischen einem Program Process Monitoring und einem Outcome Monitoring unterscheiden [RLF04]. Mit Program Process Monitoring ist die systematische und kontinuierliche Dokumentation von Kernaspekten der Programmperformanz gemeint, die feststellt ob das Programm entsprechend ursprünglicher Intentionen verläuft bzw. ob es bestimmten Standards entspricht. Outcome Monitoring hingegen beschäftigt sich mit der kontinuierlichen Beobachtung intendierter Ergebnisse. Monitoringprozesse unterstützen auf diese Weise die kontinuierliche Verbesserung von Forschungsprogrammen und liefern eine Entscheidungsgrundlage über zukünftige Projektförderungen und Programmausrichtungen [EG98].

Zur Erfüllung seiner Funktionen arbeitet das Monitoringprojekt IMO mit zwei verschiedenen Monitoringzyklen, die operativ unabhängig voneinander durchgeführt, deren inhaltliche Ergebnisse jedoch wechselseitig aufeinander bezogen werden. Auf Basis der Monitoringergebnisse werden schließlich die gewonnenen Informationen adressatengerecht aufbereitet und Handlungsempfehlungen an Akteure in Wissenschaft, Wirtschaft und Politik gegeben (siehe Abb. 1).

Im Rahmen des internen Monitoringzyklus' wird das Forschung- und Entwicklungsprogramm A-L-K beobachtet; die Reichweite der Beobachtung beschränkt sich hierbei also auf die einzelnen Förderschwerpunkte. Im Sinne eines Outcome Monitorings fokussiert der kontinuierliche Monitoringprozess die inhaltlichen Ergebnisse, die das Programm selbst hervorbringt. Hierzu werden Resultate aus den Förderschwerpunkten gesammelt, verdichtet und adressatengerecht aufbereitet. Entscheidend dabei ist, diese in Zusammenhang zu den im A-L-K aufgeworfenen Problemstellungen zu setzen und die entsprechenden Lösungsansätze herauszustellen. Im Metaprojekt StArG liegen die Ergebnisse teilweise schon verdichtet vor, wie z. B. in Form der Positionspapiere der Fokusgruppen oder des Aachener Impulses.

In einer externen Monitoringschleife wird der gesamte Themenkomplex der Innovationsfähigkeitsforschung im internationalen Raum beobachtet. Dies betrifft sowohl die erweiterte nationale und internationale Forschung als auch Best Practice Beispiele im globalen Raum sowie die politische Community Deutschlands. Die Spiegelung mit den Resultaten des externen Monitorings stellt die programminternen Forschungsergebnisse in einen internationalen Kontext und ermöglicht eine kontinuierliche inhaltliche Weiterentwicklung und Optimierung von A-L-K im Sinne eines Lernenden Programms. Die Hauptaufgabe des IMO-Projektes besteht also darin, fortlaufend die Ergebnisse der Beobachtungen der Förderschwerpunkte einerseits und die Resultate des externen Monitorings andererseits miteinander in

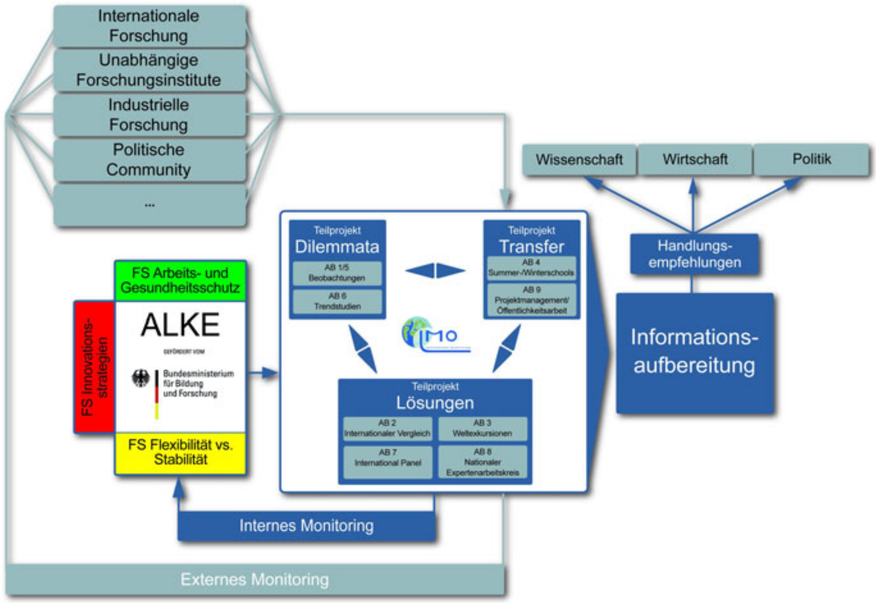

Abb. 1 Der doppelte Monitoringzyklus im Projekt IMO

Beziehung zu setzen. Um nicht nur Forschungsergebnisse sondern auch die Akteure selbst miteinander zu vernetzen und auf diese Weise eine interdisziplinäre Community zur Innovationsfähigkeitsforschung erst aufzubauen, werden im IMO-Projekt verschiedene Instrumente wie der Nationale Expertenarbeitskreis und das Internationale Panel eingesetzt. Weiterhin werden internationale Experten bspw. über (virtuelle) Konferenzen und gemeinsame Publikationen mit nationalen Experten zusammengeführt, um gemeinsam Forschungsfragen zu diskutieren und neue Forschungsbedarfe festzustellen. Auf diese Weise identifiziert das IMO-Projekt neue Fragestellungen sowie zukünftige Spannungsfelder und Trends, die dann erneut in den Forschungsprozess eingebracht werden. Auf dem Austausch von Expertenmeinungen basiert auch die operative Zusammenführung der internen und der externen Monitoringschleife. Grundsätzlich sollen die gebündelten Forschungsergebnisse der Förderschwerpunkte in einen interdisziplinären und internationalen Kontext gesetzt werden. Dieses Zusammenspiel zwischen internen und externen Monitoringprozessen lässt sich exemplarisch an der virtuellen Konferenz zum Aachener Impuls vom 26.01.2010 veranschaulichen. Zunächst hat das IMO-Projekt den Aachener Impuls als ein Resultat des Förderschwerpunkts P-A-G-S aufgenommen und in Kooperation mit dem Metaprojekt StArG ins Englische übersetzen lassen. Im Rahmen der externen Monitoringschleife organisierte und moderierte das IMO-Projekt dann eine virtuelle Konferenz, in der das Positionspapier von internationalen Experten aus

Europa und den USA kommentiert und um weitere Forschungsbedarfe sowie bereits existierende Lösungsansätze im internationalen Kontext ergänzt wurde[1].

3 Sozioökonomische Spannungsfelder und ihr Zusammenhang mit dem Präventiven Arbeits- und Gesundheitsschutz

Um die heterogenen Ausführungen rund um das Thema Innovationsfähigkeit vernetzen und in gemeinsame Sinnzusammenhänge bringen zu können, orientiert sich das IMO-Projekt an ausgewählten Dilemmata, die als allgemeine sozioökonomische Spannungsfelder der heutigen Arbeits- und Lebenswelt anzusehen sind[2].

Auf der Basis umfangreicher Expertenbefragungen [BSH09] hat das IMO-Projekt aus der Vielzahl möglicher und praxisrelevanter Spannungsfelder vier elementare Dilemmata extrahiert (siehe Abb. 2). Diese dienen einerseits als Grundstruktur für die Bündelung, Zusammenführung und Darstellung der Forschungsresultate und Lösungsansätze im Rahmen des internen und externen Monitorings. Sie bilden damit ein entscheidendes Fundament für die interdisziplinäre Wissensarbeit und die adressatengerechte Aufbereitung wissenschaftlicher Ergebnisse. Andererseits repräsentieren die selektierten Dilemmata die wichtigsten sozioökonomischen Spannungsfelder und Probleme der modernen Arbeitswelt für den Wirtschaftsstandort Deutschland. Aus Projektsicht sind es mithin diese zentralen Herausforderungen, die Individuen, Organisationen, Netzwerke und Gesellschaft auf dem Weg zur Innovations- und globalen Wettbewerbsfähigkeit zu bewältigen haben:

- Verantwortlicher Umgang mit Humanressourcen vs. Kostendruck,
- Langfristige Strategien zur Erhöhung der Innovationsfähigkeit vs. Erfolgsdruck,
- Zeit für Lernprozesse vs. Zeitdruck,
- Stabilitätsbedarf vs. Flexibilisierungsdruck.

Diese vier Hauptdilemmata bilden mithin die grundsätzliche Problemumwelt ab, mit der Akteure in einer modernen Arbeitswelt umgehen müssen. Aus Projektsicht lassen sie sich auf einem höheren Abstraktionslevel zu einem übergeordneten Problemkomplex, dem Metadilemma **Nachhaltigkeit vs. Kurzfristige Gewinnmaximierung**, zusammenführen. Dieses lässt sich im Hintergrund nahezu aller aktueller

[1] Neben Dr. Sabine Reszies vom Redaktionsteam des Aachener Impulses und Dr. Claudius Riegler vom Projektträger DLR nahmen Prof. Dr. Frank Emspak (USA), Dr. Francesco Garibaldo (Italien), Prof. Dr. Annika Lantz-Friedrich (Schweden), Dr. Tarja Tikkanen (Norway), Prof. Dr. Peter Totterdill (UK), Prof. Dr. Gerard Zwetslot (Netherlands) an der virtuellen Konferenz teil. Das Ergebnisprotokoll zur Konferenz findet sich auf der IMO-Homepage unter: http://www.internationalmonitoring.com/fileadmin/Downloads/VCs/%5BIMO%5D_Minutes_Virtual_Live_Conference_Jan.%202010.pdf [Stand: 20.02.2010].

[2] Die im Folgenden skizzierten Dilemmata finden sich in leicht abgewandelter Form in der Bekanntmachung zum Programm „Arbeiten, Lernen, Kompetenzen entwickeln – Innovationsfähigkeit in einer modernen Arbeitswelt“ wieder. Vgl.: http://www.bmbf.de/pub/innovationsfaehigkeit_arbeitswelt.pdf [20.02.2010].

Abb. 2 Dilemmata der Innovationsfähigkeit

Diskussionen der humanorientierten und auch ökonomischen Innovationsforschung (und darüber hinaus) wiederfinden. Aufgrund seiner Reichweite, seines hohen Abstraktionslevels sowie seiner fundamentalen wirtschaftstheoretischen Bedeutung ist das Spannungsfeld **Nachhaltigkeit vs. Kurzfristige Gewinnmaximierung** als Metadilemma des wirtschaftlichen Handelns im Allgemeinen und der Manifestierung und Steigerung der Innovationsfähigkeit im Besonderen anzusehen – eine Perspektive, die sich auch in den aktuellen Diskussionen zu Ursachen und Wirkungen der globalen Finanz- und Wirtschaftskrise spiegelt.

Das IMO-Projekt bündelt Forschungsergebnisse der internen und externen Monitoringprozesse und bringt sie mit den jeweiligen Dilemmata in Zusammenhang. Dabei ist es entscheidend, dass die verschiedenen Methoden und Erkenntnisse aus der Wissenschaft nicht zu einer Auflösung der Dilemmata, sondern i. d. R. allenfalls zu einer Reduktion beitragen können. Letztlich geht es also weniger darum, ein Dilemma gänzlich lösen zu wollen, anstatt vielmehr darum, mit einem grundsätzlichen Problem in effizienter Weise umzugehen. Da die Spannungsfelder selbst eng miteinander verknüpft und daher nicht trennscharf voneinander zu unterscheiden sind, haben Ansätze zur Reduktion und zum Umgang mit einem Dilemma stets auch Einfluss auf die anderen. Im Folgenden werden zunächst das Metadilemma und im Anschluss die vier subsumierten Hauptdilemmata in ihren charakteristischen Merkmalen beschrieben. Anhand exemplarischer Forschungsergebnisse und Problemstellungen aus dem Förderschwerpunkt P-A-G-S werden die wechselseitigen Beziehungen des Präventiven Arbeits- und Gesundheitsschutzes mit den Spannungsfeldern skizziert (Abschn. 3.1–3.5).

Über die Dilemmata und deren Reduktionsansätze hinaus hat das IMO-Projekt drei wissenschaftliche Querschnittsfelder identifiziert (siehe Abb. 3):

- Operationalisierung und Bewertung,
- Vernetzung und Methodenintegration,
- Befähigung und Umsetzung.

Diese Querschnittsfelder umfassen entscheidende, praxisorientierte und spannungsfeldübergreifende Forschungsaufgaben, deren Lösungen direkte Effekte zur Steigerung der Innovationsfähigkeit in der wirtschaftlichen Praxis wie auch produktive Rückwirkungen auf die wissenschaftliche Theoriebildung versprechen. Die drei Querschnittsfelder werden im Sinne einer integrierten Querschnittsforschung innerhalb von Förderschwerpunkten im Anschluss an die Darstellung der Dilemmata (Abschn. 4) skizziert.

3.1 Metadilemma: Nachhaltigkeit vs. Kurzfristige Gewinnmaximierung

> Es ist die Gewinnmaximierungsdoktrin selbst, die letztlich den Zwang zu rücksichtslosem Wirtschaften erzeugt. (Peter Ulrich)[3]

Das Spannungsfeld Nachhaltigkeit vs. Kurzfristige Gewinnmaximierung bezeichnet die Problematik eines vorausschauenden, verantwortlichen sowie dauerhaft erfolgreichen Managements unter der rein ökonomischen Maxime der (kurzfristigen) Realisierung größtmöglicher Gewinne. Das IMO-Projekt betrachtet das Dilemma dabei nicht allein als ein Shareholder-Value-Problem, sondern als eine grundlegende Schwierigkeit von Managementaufgaben in profitorientierten Wirtschaftsbereichen. Damit betrifft dieses Spannungsfeld nicht nur Organisationen. Auch Individuen, Netzwerke und Gesellschaften stehen vor dem Problem, dass nachhaltige Entwicklungen mit einer ökonomisch einseitigen und kurzfristig ausgerichteten Gewinnmaximierung im Widerspruch stehen.

In diesem Widerspruch treffen letztlich zwei Paradigmen der Wirtschaftstheorie aufeinander:

- Die (neo)klassische Reduktion und Konzentration der Unternehmensziele auf den eigenen größtmöglichen monetären Gewinn. Diese radikal marktorientierte Maxime ist in den schnelllebigen Wirtschafts- und Finanzsystemen von heute gepaart mit einer auf stetigem Erfolgsdruck basierenden Kurzatmigkeit des Handelns. Unternehmen verfolgen in dieser Perspektive rein ökonomische Ziele.

[3] Zitiert aus einem Interview der FAZ, 12.07.2009.

- Die systemische Einsicht in die Grenzen des Wachstums und die daraus resultierende Forderung nach einem verantwortungsbewussten wirtschaftlichen Handeln, das langfristige Stabilität gewährleistet. Das zukunftsorientierte Prinzip der Nachhaltigkeit überschreitet dabei die traditionellen Grenzen der Disziplinen und verfolgt einen holistischen Ansatz, der die ökonomische Perspektive um die soziale und ökologische erweitert.

Der Tendenz zu dieser erweiterten Verantwortung von Unternehmen steht die Unvereinbarkeit mit der Doktrin zur Gewinnmaximierung gegenüber, die Wirtschaftssubjekte zu rücksichtslosem Handeln zwingt. Vor diesem Hintergrund ist die einseitige Fokussierung auf den größtmöglichen monetären Gewinn nicht mehr aufrecht zu erhalten [Thi09]. Rein monetäre Gewinnmaximierung wird abgelöst durch Gewinnstreben und erweitert um soziale und ökologische Verantwortung.

Obschon eine nachhaltige Entwicklung stets als gesamtgesellschaftliche Aufgabe anzusehen ist und damit Anforderungen an alle sozialen Akteure stellt, kommt Unternehmen durch ihren starken sozioökonomischen Einfluss ein besonderes Gewicht und eine besondere Verantwortung zu. Mit dem Prinzip der **Corporate Social Responsibility** (CSR) tragen Organisationen wesentlich zu einer nachhaltigen Entwicklung in den Bereichen Markt, Umwelt, Arbeitsplatz und Gemeinwesen bei [nat09]. Dabei führt das wachsende globale Bewusstsein für Umwelt- und Sozialbelange nicht nur zu einem Aufleben und zur Integration des Nachhaltigkeitsgedankens innerhalb der Wirtschaft, sondern wertet Nachhaltigkeit mehr und mehr zu einem eigenen Wettbewerbsvorteil auf [Mic06].

Im Bereich des Arbeits- und Gesundheitsschutzes zeigen insbesondere die zentralen Begriffe der Prävention und Salutogenese das sich wandelnde Verständnis zu einem mehr und mehr zukunftorientierten und nachhaltigen wirtschaftlichen Handeln – auch wenn die Verknüpfung von CSR mit Maßnahmen der präventiven Gesundheitsförderung noch in ihren Anfängen steckt (Aachener Impuls). Ein Grund für die bisher mangelnde Integration könnte darin liegen, dass unternehmerische Maßnahmen zur CSR häufig mehr durch Gewinnmaximierung statt durch Verantwortungsbewusstsein motiviert sind [Cro05]. Dadurch stehen populistische Maßnahmen zur Steigerung der Kundenbindung eher im Fokus als innerbetriebliche Präventionsstrategien.

3.2 Verantwortlicher Umgang mit Humanressourcen vs. Kostendruck

Das Dilemma Verantwortlicher Umgang mit Humanressourcen vs. Kostendruck beschreibt den Anspruch an ein umfassendes, weitsichtiges und verantwortungsbewusstes Management von personengebundenen Wissenspotenzialen, Fähigkeiten und Kompetenzen unter dem gleichzeitigen ökonomischen Druck zur Senkung von Ausgaben. Dieses Spannungsfeld bewegt sich mithin innerhalb der sozialen Dimension der Nachhaltigkeitsfrage und bezieht sich primär, wenn auch nicht ausschließlich, auf den Umgang von Organisationen mit den zur Verfügung stehenden Humanpotentialen der Mitarbeiter.

Der Abschied von einer rein technik- und produktorientierten Sicht auf Innovationen wertet die immateriellen Faktoren innerhalb von Innovationsprozessen auf [HKS08]. Mit dem Begriff der Innovations*fähigkeit* rücken zunehmend Menschen und damit soziale Prozesse als die entscheidenden **Enabler von Innovationen** in den Fokus. Die Wissensarbeit avanciert im Zuge der Tertiarisierung und Quartarisierung zur zentralen Gestalt fortgeschrittener Ökonomien, die Menschen als Wissensträger zum wichtigsten Innovations- und Wettbewerbsfaktor [Edv02, db]. Im Widerspruch zur gestiegenen Wertschätzung des „Faktors Mensch" konzentrieren sich Organisationen unter steigendem Kostendruck nicht selten auf Arbeitskostenreduktion und kurzfristige Gewinnmaximierung anstatt auf nachhaltige Zukunftssicherung. Der Paradigmenwechsel in der Wahrnehmung des Arbeiters vom früheren Kostenfaktor zum heutigen Vermögenswert ist in der Praxis wirtschaftlichen Handelns noch nicht vollzogen [Dru].

Dabei erhält das Spannungsfeld Verantwortlicher Umgang mit Humanressourcen vs. Kostendruck zusätzliche Nahrung durch die zunehmende Flexibilisierung der Arbeitsformen und die damit verbundene Diskontinuität der Erwerbsbiographien. Verkürzte Planungszeiträume und Kostendruck wirken der erwartbaren Amortisierung von Investitionen in individuelle Personalmaßnahmen entgegen. Mit anderen Worten: Die Entscheidungsträger können nie sicher sein, ob die jeweils geförderten Mitarbeiter lange genug im Unternehmen sind, damit sich entsprechende Investitionen lohnen.

Der nur vage plan- und bewertbare ökonomische Nutzen gilt mithin auch als eine der Hauptursachen für die mangelnde Bereitschaft, insbesondere von KMU, zu langfristigen und nachhaltig wirksamen Maßnahmen der präventiven Gesundheitsförderung. Es besteht in diesem Zusammenhang durchaus die Gefahr, dass sich ein verantwortlicher Umgang mit Humanressourcen im Allgemeinen und betrieblichen Gesundheitsmaßnahmen im Speziellen auf einen immer kleineren Kreis von zentralen und langfristig mit dem Unternehmen verbundenen Schlüsselpersonen beschränkt (Kernbelegschaft), während die zunehmende Anzahl an Freien Mitarbeitern und Teilzeitkräften von diesen Maßnahmen ausgeschlossen bleiben (Randbelegschaft).

3.3 Langfristige Strategien zur Erhöhung der Innovationsfähigkeit vs. Erfolgsdruck

Das Dilemma Langfristige Strategien zur Erhöhung der Innovationsfähigkeit vs. Erfolgsdruck beschreibt die zunehmende Anforderung an grundsätzliche strukturelle und prozessuale Veränderungen in Organisationen und Gesellschaften zur Stärkung der Innovationsfähigkeit unter den Vorgaben möglichst schneller Erfolge. Im Rahmen der Innovationsfähigkeitsforschung umfasst der strategische Wandel dabei primär soziale und organisationale Entwicklungen, die unter dem Paradigma technologisch orientierter Produktinnovationen vor allem in der betrieblichen Praxis bislang wenig Beachtung finden. Das IMO-Projekt betrachtet den Faktor Erfolg daher auch nicht allein als monetäre Größe, sondern als allgemeine Übereinstimmung der Ergebnisse von langfristigen Veränderungsprozessen mit den jeweiligen Zielvorstellungen.

Aufgrund der allgemeinen Ausrichtung auf Veränderungsprozesse findet sich das Dilemma Langfristige Strategien zur Erhöhung der Innovationsfähigkeit vs. Erfolgsdruck in allen untersuchten Spannungsfeldern wieder. Im Zuge der wachsenden Komplexität und Dynamik innerhalb der Arbeitswelt [HHH09] sowie der steigenden Bedeutung von immateriellen Faktoren sind neue Ansätze und Methoden gefragt, um die zentrale Frage nach einer ökonomischen Entscheidungsgrundlage von komplexen Veränderungsprozessen zu beantworten.

Im Förderschwerpunkt „Präventiver Arbeits- und Gesundheitsschutz" konnten verschiedene Analyse- und Benchmarkinginstrumente, wie z. B. der Gesundheitsindex [SSS], entwickelt werden, mit denen sich die Zusammenhänge zwischen einem nachhaltigen Gesundheitsmanagement und ökonomisch relevanten Nutzen identifizieren und bewerten lassen. Dennoch mangelt es auch im Arbeits- und Gesundheitsschutz nach wie vor an empirischen Daten (z. B. zum Zusammenhang zwischen Präventionsmaßnahmen und Unternehmensperformance) und teilweise auch an geeigneten Operationalisierungsmethoden, um die Erfolge von Maßnahmen der präventiven Gesundheitsförderung über die rein ökonomischen Kennzahlen hinaus einschätzen zu können – und damit ist zunächst einmal nur die Möglichkeit zur Bewertung gewährleistet, nicht aber die tatsächliche Realisierung und Nutzung dieser Möglichkeit als Entscheidungsgrundlage in der Praxis wirtschaftlichen Handelns.

3.4 Zeit für Lernprozesse vs. Zeitdruck

Das Dilemma Zeit für Lernprozesse vs. Zeitdruck beschreibt die individuelle, organisationale und gesellschaftliche Notwendigkeit von Lern- und Entwicklungsprozessen unter den Bedingungen eines zunehmenden zeitlichen Arbeitsaufwands. Dabei adressiert das Spannungsfeld einerseits den Zeitdruck des Individuums, dessen Konsequenzen sich in Stress, Unsicherheit und wachsenden psychischen Belastungen zeigen. Andererseits stehen jedoch auch Unternehmen im Zuge der Globalisierung, Dynamisierung und Flexibilisierung der Wirtschaft unter einem erhöhten Zeitdruck des operativen Arbeitsalltags, wie er sich bspw. in der Vernachlässigung von Entwicklungs- und Veränderungsprozessen, mangelndem Kundenservice oder einer innovationshemmenden Unternehmenskultur niederschlägt. In diesem Sinne ist Zeitdruck vor allem auf organisationaler Ebene ein Spiegelbild des ökonomisch bedingten Kosten-, Erfolgs- und Flexibilisierungsdrucks. Letztlich lässt sich sogar auf gesellschaftlicher Ebene ein zunehmender Zeitdruck ausmachen, der sich durch eine übergreifende Verkürzung von Lebensphasen und der damit verbundenen sozialen Beschleunigung charakterisiert [Ros05].

Da Innovationen in entscheidender Weise vom Humanpotential der Mitarbeiter und der Entwicklungsbereitschaft der Unternehmen abhängen, sind fehlende Lernprozesse als Folge vom Zeitdruck operativer Aufgaben wesentliche Blockaden von Innovationsfähigkeit. Für das Individuum stellt sich vor diesem Hintergrund also die Frage der Vereinbarkeit von Arbeiten und Lernen unter den verschärften Bedingungen der modernen Arbeitswelt. Aus Unternehmenssicht sind vor allem neue Ideen zur integrativen Gestaltung von Lern- und Arbeitswelten gefragt, die sowohl einen verantwortlichen und innovationsfördernden Umgang mit Humanressourcen ermöglichen als auch die organisationalen Prozesse und Strukturen den veränderten Anforderungen einer globalisierten Wirtschafts- und sich wandelnden Arbeitswelt anpassen. Auf gesellschaftlicher Ebene sind primär die Auswirkungen des demographischen Wandels aufzufangen. Hier besteht die Aufgaben darin, möglichst alle gesellschaftlichen Gruppen über die verschiedenen Lebensphasen hinweg am Arbeitsprozess zu beteiligen und damit Beschäftigungsfähigkeit bis ins hohe Alter, Integration von Menschen mit Behinderung, Chancengleichheit sowie die Vereinbarkeit von Beruf und Familie zu gewährleisten [Bau]. Um diese Ziele zu erreichen, ist ein übergreifender Wandel des Bildungsverständnisses notwendig – von der faktenorientierten Wissensvermittlung zur kompetenzorientierten Befähigung [Dah09].

Das Spannungsfeld Zeit für Lernprozesse vs. Zeitdruck ist besonders eng mit dem Arbeits- und Gesundheitsschutz verknüpft. Dabei bedingen sich Gesunderhaltung und Kompetenzentwicklung gegenseitig. Einerseits ist die Gesundherhaltung eine entscheidende Voraussetzung für die notwendige lebenslange Kompetenzentwicklung und eine kontinuierliche Beschäftigungsfähigkeit [Sti09]. Andererseits verlangt gerade die partizipative Präventionspraxis sowie eine zunehmende Eigenverantwortung für die individuelle Gesundheit die Ausbildung einer umfassenden Gesundheitskompetenz [Pfa08, NFF07]. Diese Kompetenzen zum gesundheitlichen Selbstmanagement gilt es in neue Konzepte zur Entwicklung von Schlüsselqualifikationen und elementaren Persönlichkeits- und Lebenskompetenzen zu integrieren. Vor dem Hintergrund des steigenden individuellen und organisationalen Zeitdrucks ist es dabei entscheidend, dass diese Metakompetenzen bewussten und expliziten Einzug in die schulische und universitäre Aus- sowie die arbeitsplatzintegrierte berufliche Weiterbildung finden [Opa06].

3.5 Stabilitätsbedarf vs. Flexibilisierungsdruck

Das Dilemma Stabilitätsbedarf vs. Flexibilisierungsdruck beschreibt das Verlangen von Individuen, Organisationen, Netzwerken und Gesellschaften nach Sicherheit in gegenwärtigen und Planbarkeit von zukünftigen Prozessen unter dem steigenden ökonomischen und sozialen Druck zum permanenten Wandel, zur kontinuierlichen Anpassung und der damit verbundenen Auflösung bestehender Strukturen. Neben der strukturellen Perspektive der Flexibilisierung umfasst dieses Spannungsfeld also auch die prozessuale Sicht der Dynamisierung, der Beschleunigung und des Wandels. Das Dilemma Stabilitätsbedarf vs. Flexibilisierungsdruck wird somit als Kehrseite des Dilemmas Entschleunigungsbedarf vs. Dynamisierungsdruck erkannt.

Der Druck zur Prozessbeschleunigung und zur Flexibilisierung entsteht primär aus dem Drang kontinuierlicher Produktivitäts- und Gewinnsteigerungen in einem globalisierten Wettbewerb. Die Folgen für die Arbeits- und Lebenswelt sind gravierend und zeigen sich im gesamten Spektrum von allgemeiner sozialer Beschleunigung bis zu individuellen psychischen Krankheiten. Auf der anderen Seite ermöglicht gerade Flexibilität ein Höchstmaß an Handlungsfähigkeit, Selbstbestimmung und Freiheit unter zunehmend dynamischen und komplexen Bedingungen der Wirtschafts-, Arbeits- und Lebenswelt. Auch die Fähigkeit, neue Ideen zu kreieren und Innovationen durchzusetzen beruht in entscheidender Weise auf flexiblen und dynamischen Denk- und Arbeitsprozessen. Es ist also umso entscheidender, die richtige Balance zwischen Flexibilisierung und Stabilität sowie zwischen Dynamik und Entschleunigung zu finden, um optimale Bedingungen für innovations- und wettbewerbsfähige Menschen, Unternehmen, Netzwerke und Gesellschaften zu etablieren [HHH09].

Anknüpfungspunkte zum Arbeits- und Gesundheitsschutz hat das Dilemma Stabilitätsbedarf vs. Flexibilisierungsdruck vor allem auf individueller und organisationaler Ebene. Gerade die zunehmenden psychischen Belastungen sowie die damit einhergehende Demotivations-, Frustrations- und Angsttendenzen werfen die Frage nach den Grenzen von Flexibilisierung und Prozessbeschleunigung auf. Neben Maßnahmen zur Work-Life-Balance, wie sie aktuell im Rahmen der entsprechenden Fokusgruppe im Förderschwerpunkt Balance zwischen Flexibilität und Stabilität untersucht werden sowie Methoden zum Umgang mit Ungewissheit [BW09], sind es vor allem auf Nachhaltigkeit ausgerichtete High-Road-Ansätze der Arbeitsorganisation [Tot], durch welche sich die gesundheitsbeeinträchtigenden Konsequenzen von Flexibilisierung und Prozessbeschleunigung in der heutigen und zukünftigen Arbeitswelt abfedern lassen.

4 Empfehlung: Querschnittsforschung in Förderschwerpunkten

Das IMO-Projekt hat drei Forschungsfelder identifiziert, die quer zu allen adressierten Dilemmata verlaufen und grundsätzliche Probleme an der Schnittstelle von Wissenschaft und Praxis adressieren: **Operationalisierung und Bewertung, Vernetzung und Methoden-integration** sowie **Befähigung und Umsetzung** (siehe Abb. 3). Lösungsansätze in diesen Bereichen können mithin als übergreifende Maßnahmen zur Reduktion aller Spannungsfelder und damit als allgemeine Treiber von Innovationsfähigkeit angesehen werden.

Aus Projektsicht lassen sich die genannten Felder zu einer themenübergreifenden Forschungstrias mit drei zentralen Aufgaben integrieren:

1. **Operationalisierung und Bewertung:** Die praktische Messbarmachung von theoretischen Konzepten und wissenschaftlichen Lösungsansätzen sowie die ganzheitliche Bewertung qualitativer und komplexer Einflussfaktoren.

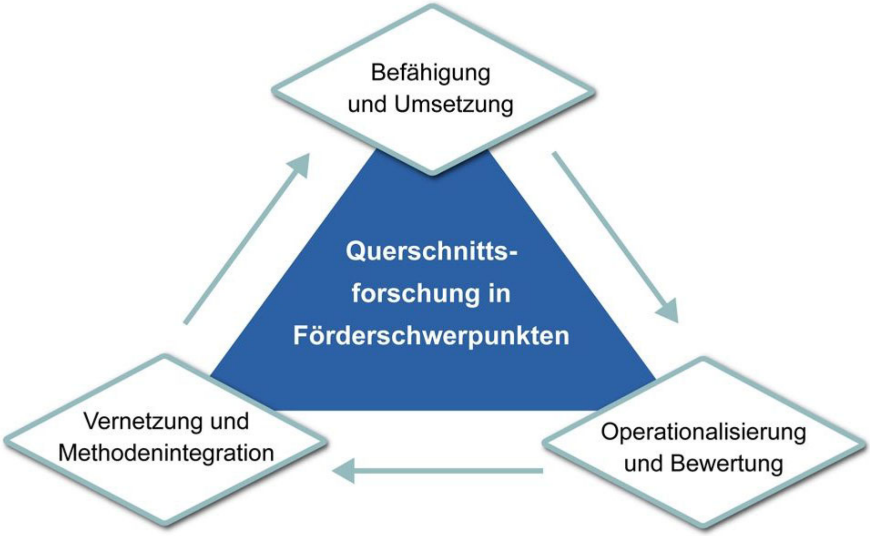

Abb. 3 Querschnittsforschung in Förderschwerpunkten als Treiber von Innovationsfähigkeit

2. **Vernetzung und Methodenintegration:** Die Identifikation und Zusammenführung von relevanten Akteuren sowie die Integration, Anpassung und praktische Nutzbarmachung vorhandener Methoden und Lösungsansätze aus der Forschung für die wirtschaftliche Praxis.
3. **Befähigung und Umsetzung:** Die begleitende und interaktive Umsetzung individualisierter Strategien und Methoden in der wirtschaftlichen Praxis sowie die Rückführung gewonnener Erkenntnisse in die Prozesse der Mess- und Nutzbarmachung.

Eine so verstandene Querschnittsforschung bewegt sich in den bislang kaum besetzten Zwischenräumen von wissenschaftlicher Theorie und wirtschaftlicher Praxis. An dieser Schnittstelle steht im Gegensatz zum traditionellen Forschungsverständnis nicht die Entwicklung neuer Methoden und die Generierung von theoretischem Wissen im Vordergrund. Das Ziel ist vielmehr, disziplinübergreifend geeignete und vorhandene Konzepte aus dem kaum überschaubaren Wissensvorrat der Forschung für die Praxis aufzubereiten und nutzbar zu machen sowie im Zuge der Vernetzung relevanter Akteure in der Praxis einzuführen und umzusetzen.

Dabei verspricht eine verstärkte und explizite Förderung der genannten Querschnittsforschung Synergieeffekte sowohl auf Seiten der Wissenschaft als auch auf Seiten wirtschaftlicher Praxis. Mit den innovativen Strukturen der aktuellen Förderschwerpunkte hat das BMBF bereits im Programm A-L-K wichtige Schritte in diese Richtung unternommen. So stärken Verbundprojekte innerhalb der Förderschwerpunkte die Streuung und Umsetzung wissenschaftlicher Erkenntnisse und Methoden in der wirtschaftlichen Praxis. Fokusgruppen und Metaprojekte führen zudem relevante Akteure aus Forschung, Wirtschaft und Politik zusammen und unterstützen die Integration von entwickelten Methoden aus verschiedenen Projekten und Forschungsbereichen. Die Aufnahme jeweils einer schwerpunktsinternen Untersuchung in den beiden laufenden Förderschwerpunkten adressiert hingegen explizit die Messbarmachung von theoretischen Konzepten und die Bewertung weicher Faktoren im Rahmen der Innovationsfähigkeitsforschung. Das IMO-Projekt empfiehlt für die Ausgestaltung wieterer Förderschwerpunkte sowie kommender Forschungs- und Entwicklungsprogramme eine Intensivierung dieser Maßnahmen im Sinne einer triadischen Querschnittsforschung mit den oben erwähnten Aufgaben und Zielen.

Im Folgenden werden die drei Aufgabenfelder kurz skizziert und in ihren grundsätzlichen Merkmalen charakterisiert.

4.1 Operationalisierung und Bewertung

Die Fähigkeit von Individuen, Organisationen, Netzwerken und Gesellschaften zur Hervorbringung von Innovationen hängt in entscheidendem Maße von weichen Faktoren ab. Der komplexe Einfluss von Humanpotentialen, Lernprozessen oder organisationalen Veränderungen lässt sich durch zahlenorientierte Operationalisierungs- und Bewertungsmethoden nicht hinreichend fassbar machen und wird allzu häufig durch die Reduktion auf rein monetäre Konsequenzen in seinen vielschichtigen Ausprägungen verzerrt. Auf der anderen Seite beruht eine Selektion von geeigneten Strategien, Methoden und Maßnahmen in diesen Bereichen auf möglichst objektiven Bewertungen, die eine Vergleichbarkeit und gemeinsame Operationalisierungsverfahren voraussetzen. Letztlich ist die Frage nach positiven und negativen Einflussfaktoren von Innovationsfähigkeit und damit die Frage nach dem Konzept 'Innovationsfähigkeit' im Allgemeinen auf reliable und valide Operationalisierungs- und Bewertungsmethoden angewiesen. Dabei mangelt es häufig nicht daran, dass es keinerlei Methoden gibt, sondern daran, dass vorhandene Methoden die komplexen Untersuchungsphänomene oft nur unzureichend abbilden, nicht allgemein anwendbar sind und keine verbreitete Akzeptanz finden. Gerade das letztgenannte Problem ist auch eine Frage der praktischen Nutzbarmachung und Verbreitung von vorhandenen Instrumenten. So mangelt es im Bereich des Arbeits- und Gesundheitsschutzes z. B. an geeigneten, allgemein akzeptierten, in Managementpraktiken implementierten und praktisch eingesetzten Operationalisierungs- und Evaluierungsmethoden bei der Bewertung von

- (partizipativen) Präventionsstrategien,
- psychischen Belastungen im Arbeitsprozess,
- Investitionen in die Gesundheitsförderung,
- Maßnahmen zur Kompetenzentwicklung,
- Veränderungen der Arbeitsorganisation,
- Maßnahmen zur Work-Life-Balance.

4.2 Vernetzung und Methodenintegration

Die fachlichen Spezifizierungen und die insgesamt immer noch unterentwickelten Fähigkeiten zur und auch Bemühungen um Interdisziplinarität haben zu einer heterogenen Methodenvielfalt in den Wissenschaften geführt. So ist die mangelnde Verbreitung von wissenschaftlichen Erkenntnissen, Verfahren und Lösungsansätzen in der wirtschaftlichen Praxis nicht nur eine Folge begrenzter Anwendungsmöglichkeiten, sondern auch eine Folge der fehlenden Integration verfügbarer Methoden. Gerade unter dem steigenden Zeit- und Kostendruck und insbesondere für KMU ist es nahezu unmöglich, die Vielfalt vorhandener Methoden in ihrer ganzen Breite einzusetzen: So sind z. B. verschiedene Methoden des Innovationsmanagements, Wissensmanagements, IC-Managements, Projektmanagements, Change-Managements und Gesundheitsmanagements im operativen Arbeitsalltag nicht parallel ein- und umsetzbar. Vor diesem Hintergrund ist es entscheidend, vorhandene Ansätze aus den verschiedenen Forschungsbereichen zu interdisziplinären und integrierten Lösungen zusammenzuführen.

Um eine tatsächliche Implementierung von (integrierten) Methoden jedoch optimal vorzubereiten, bedarf es über die theoretische Zusammenführung von Inhalten hinaus auch einer praktischen Zusammenführung relevanter Akteure und Institutionen aus Forschung und wirtschaftlicher Praxis. Nur über Vernetzung und intensiven Austausch lassen sich die theoretischen Inhalte der Wissenschaft an die jeweiligen praktischen Bedarfe der Unternehmen anpassen und für diese nutzbar machen. Einen ersten Hebel dazu bietet das Instrument der Fokusgruppen und Metaprojekte. Diese könnten sich zukünftig als zentraler Bereich interdisziplinärer Methodenintegration der Arbeits- und Lernforschung nutzbar machen. Dabei sind über die notwendige Zusammenführung von Wissenschaft und Praxis hinaus auch praxis- und forschungsinterne Vernetzungen von großer Bedeutung. Für das Programm A-L-K stellt sich in diesem Zusammenhang z. B. aber auch die Frage nach den Vernetzungs- und Integrationsmöglichkeiten mit den übrigen Forschungsfeldern der Hightech-Strategie.

Innerhalb des Förderschwerpunkts P-A-G-S empfiehlt insbesondere die Fokusgruppe „Überbetriebliche Allianzen" eine stärkere Kooperation und Vernetzung von Kammern, Verbänden, Dienstleistern und Fachinstitutionen des Arbeits- und Gesundheitsschutzes. Im Sinne neuer und nachhaltiger Akteurs- und Dienstleistungsallianzen spielen also neben den in der Verbundforschung traditionell eingebundenen ökonomischen Entscheidungsträgern vor allem die identifizierten Intermediäre eine zentrale Rolle. Stabile Kooperationsbeziehungen zwischen allen Beteiligten des Arbeits- und Gesundheitsschutzes sorgen demnach einerseits für die Entwicklung zielgruppengerechter Methoden und Präventionsinstrumente. Andererseits sind diese überbetrieblichen Netzwerke eine entscheidende Voraussetzung für einen breitenwirksame Umsetzung entwickelter Lösungsansätze in der betrieblichen Praxis.[4]

[4] Die Ausführungen basieren auf den Ergebnissen der Fokusgruppe „Überbetriebliche Allianzen" zur 3. Tagung des Förderschwerpunkts „Präventiver Arbeits- und Gesundheitsschutz" in Aachen,

4.3 Befähigung und Umsetzung

Die klassische Idee des Transfers zwischen Wissenschaft und Praxis ist gescheitert. Das zugrundeliegende Modell eines wissenschaffenden Senders und eines wissennutzenden Empfängers wird den komplexen Kommunikationsprozessen zwischen theoretischen Formulierungen und praktischen Ausführungen nicht gerecht und kann eine hinreichende Anwendung und Implementierung von wissenschaftlichen Erkenntnissen und Methoden nicht gewährleisten.[5] Von den mannigfaltigen Forschungsergebnissen aus verschiedenen wissenschaftlichen Teilbereichen findet lediglich ein minimaler Anteil den Weg in die wirtschaftliche Praxis. Die erhoffte eigendynamische Dissemination von hervorragenden theoretischen Ergebnissen und auch prototypisch gelungenen praktischen Implementierungen im Rahmen von Verbundprojekten ist in der Vergangenheit vielfach ausgeblieben. Aus Projektsicht fehlt der Idee des Transfers das aktive Moment der praktischen Umsetzung und sollte daher von der Idee der Befähigung abgelöst werden.

Während intermediäre Institutionen in anderen Ländern (bspw. NCPP in Irland, IpL in Italien, UKWON in Großbritannien oder KOWIN in Korea) die Wirtschaftsakteure bei der Reflexion von Forschungsergebnissen und der Implementierung von Methoden unterstützen, ist die Schnittstelle zwischen wissenschaftlicher Theorie und wirtschaftlicher Praxis in Deutschland nach wie vor publikationsorientiert oder auf prototypische Umsetzungen mit wenig nachhaltiger Breitenwirkung ausgerichtet; es fehlt an proaktiver Wissensvermittlung und Befähigung durch einzelne Akteure oder Institutionen.

Zur Befähigung von Akteuren und zur Umsetzung von wissenschaftlichen Ergebnissen in der wirtschaftlichen Praxis bieten sich neue Ansätze der Aktionsforschung an, wie sie im Rahmen des A-L-K Förderschwerpunkts "Innovationsstrategien jenseits traditionellem Managements" untersucht werden. Primär lassen sich diese Ansätze durch folgende Merkmale charakterisieren[6]:

- Verbindung von Theorie und Praxis, indem Forscher und Betroffene wechselseitige, gemeinsame und praxisorientierte Lern- und Reflexionsprozesse ins Zentrum rücken,
- Forscher werden zu aktiv "involvierten" Praxisberatern,
- forschungsoffene Praktiker und praxisorientierte Forscher sind Voraussetzung für eine gegenseitige Akzeptanz und Gleichberechtigung,
- Organisation von Wandel und Lernen mit Fokus auf die konkrete Umsetzung von Wandel und Lernen,

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Oktober 2009, die in z. T. unveröffentlichten Positionspapieren festgehalten wurden und über das Metaprojekt StArG bezogen werden können.

[5] Das IMO-Projekt adressiert diese Problematik mit dem Dilemma Explizites Wissen vs. Implizites Wissen.

[6] Die im Folgenden vorgestellten Merkmale und Chancen basieren auf den Ergebnissen der Fokusgruppen und Projekte zur 1. Tagung des Förderschwerpunkts „Innovationsstrategien jenseits traditionellen Managements" in Berlin, Oktober 2009, die in z. T. unveröffentlichten Positionspapieren festgehalten wurden und über das Metaprojekt StArG bezogen werden können.

- Rückkopplungsschleifen (reflexive Lernprozesse) zu jedem Zeitpunkt des Forschungsprozesses,
- promptes Feedback,
- Priorisierung von praxisrelevanten Veränderungen vor konzeptionellen Erklärungen,
- Gleichzeitigkeit von Forschungs- und Interventionsmethodik,
- Bindung nützlicher Forschung an das Eingreifende und Verändernde in der Praxis (eingreifende Wissenschaft).

Die Notwendigkeit der frühzeitigen, kontinuierlichen und interaktiven Einbindung von Intermediären und Praxisakteuren in Forschungsprozesse gehört zu den entscheidenden Erkenntnissen des Förderschwerpunkts P-A-G-S. Dabei geht der postulierte Bedarf an der Ausbildung neuer Kooperationskompetenzen relevanter Akteure (Aachener Impuls) einher mit dem aus Monitoringsicht empfohlenen Paradigmenwechsel vom theorieorientierten Transfer- zum praxisorientierten Befähigungsgedanken. Vor diesem Hintergrund stellt sich die Frage, inwiefern eben diese Idee der Befähigung ein zentraler Aspekt im Rahmen neuer, innovativer und „[m]arktfähige[r] Transferstrategien“ (Aachener Impuls) wird.

5 Zusammenfassung

Der Artikel skizziert Aufgaben, Funktionen und Ergebnisse des BMBF-Projekts „International Monitoring“ (IMO) mit Bezug auf den Förderschwerpunkt „Präventiver Arbeits- und Gesundheitsschutz“ (P-A-G-S). Am Beispiel der virtuellen Konferenz zur internationalen Spiegelung des Aachener Impulses wird das Zusammenspiel interner und externer Monitoringprozesse im Bereich der internationalen Innovationsfähigkeitsforschung beschrieben. Auf der Basis dieser Prozesse verdichtet das IMO-Projekt interdisziplinäre Forschungsergebnisse und generiert Handlungsempfehlungen, die eine kontinuierliche Weiterentwicklung des Forschungs- und Entwicklungsprogramms „Arbeiten – Lernen – Kompetenzen entwickeln. Innovationsfähigkeit in einer modernen Arbeitswelt“ (A-L-K) im Sinne eines Lernenden Programms ermöglichen. Zur Strukturierung der heterogenen und vielschichtigen Ergebnisse zum Thema Innovationsfähigkeit orientiert sich das IMO-Projekt als Referenzrahmen an fünf zentralen Dilemmata, die zugleich als allgemeines sozioökonomisches Problemumfeld der modernen Arbeitswelt zu betrachten sind. Auf diese Weise lassen sich Resultate und Lösungsansätze aus verschiedenen wissenschaftlichen Disziplinen und Themengebieten in einen gemeinsamen Sinnzusammenhang bringen. Exemplarisch werden Anknüpfungspunkte und Schnittstellen zwischen den skizzierten Dilemmata und den Forschungsergebnissen und Fragestellungen des Förderschwerpunktes P-A-G-S aufgezeigt.

Der Artikel schließt mit der Empfehlung zu einer themenübergreifenden Querschnittsforschung in zukünftigen Förderschwerpunkten, die sich aus der integrierten Trias der Forschungsfelder „Operationalisierung und Bewertung“, „Vernetzung und Methodenintegration“ sowie „Befähigung um Umsetzung“ zusammensetzt.

Das IMO-Projekt sieht sich dabei durch die Ergebnisse des Förderschwerpunktes P-A-G-S bestärkt, der empirische Messmethoden und Daten ebenso als Forschungsbedarfe adressiert wie die umfassende Akteursvernetzung und ein grundsätzliches Überdenken der bisherigen Transferstrategien. Wichtige Schritte in diese Richtung sind durch die innovativen Förderstrukturen im Programm A-L-K bereits eingeleitet worden. Aus Monitoringsicht gilt es, diese Einsichten weiter auszubauen und systematisch in die Ausgestaltung kommender Förderschwerpunkte und Forschungsprogramme einfließen zu lassen.

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Potenziale für Smarte Innovation finden
Ein IT-basiertes Werkzeug zur Innovationsanalyse

Christian Tummel, Max Haberstroh, Karina Berenzen, Eckart Hauck,
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Zusammenfassung Dynamisch und komplex – so ist unsere heutige Welt, weshalb es immer schwieriger wird, Innovationspotenziale zu erkennen und diese Innovationen dann systematisch zu gestalten. Agilität kann ein Schlüssel für das Beherrschen von Dynamik und Komplexität sein, um die darin verborgenen Potenziale für Innovationen zu aktivieren. Wie aber kann identifiziert werden, welche Prozesse agiler gestaltet werden könnten, um verborgene Potenziale zu nutzen? Eine Grundlage dafür bildet das Product Lifecycle Management (PLM). Innerhalb des PLM werden alle Prozesse des Produktlebenszyklus aufgenommen, standardisiert und in ein konsistentes Datenmodell übernommen. Anhand des PLM sowie das Leben agilen Werte im Innovationsmanagement wurde im Rahmen des Projekts Smarte Innovation ein IT-basiertes Werkzeug entwickelt, welches Entscheidern innerhalb eines Unternehmens eine Hilfestellung bei der Identifizierung des eigenen Innovationspotenzials bietet. Es gibt Rückschlüsse darauf, in welchen Prozessen Strukturen und Standards ihren Sinn verloren haben, Kommunikationsprobleme auftreten oder die Kundenbindung zu schwach gelebt wird.

Schlüsselwörter: Smarte Innovationsanalyse, Storytelling, Innovationsfähigkeit, Anlagen- und Maschinenbau

1 Einleitung: Innovation als Herausforderung

Dynamisch und komplex – so ist unsere heutige Welt, weshalb es immer schwieriger wird, Innovationspotenziale zu erkennen und diese Innovationen dann systematisch zu gestalten. Häufig haben sich Strukturen und Prozesse schon so verfestigt, dass es schwer ist, das dort liegende Innovationspotential zu entdecken und zu nutzen [SU03]. Nicht nur aus Forschung und Entwicklung (FuE) gehen Innovatio-

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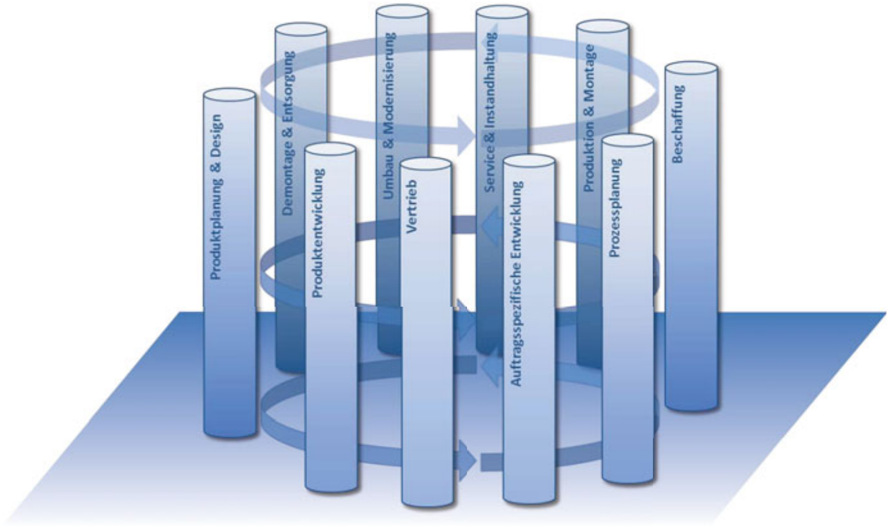

Abb. 1 Produktlebenszyklus nach [lei08]

nen hervor, sondern jeder Prozess im Produktlebenszyklus kann und muss seinen Beitrag zum Innovationsprozess leisten. Die Entwicklung von Innovation ist eine permanente Herausforderung, die es entsprechend stetig neuen Anforderungen zu gestalten gilt [IP09].

Agilität kann ein Schlüssel für das Beherrschen von Dynamik und Komplexität (siehe [Ise94]) sein, um die darin verborgenen Potenziale für Innovationen zu aktivieren. Wie aber kann identifiziert werden, welche Prozesse agiler gestaltet werden könnten, um verborgene Potenziale zu nutzen? Eine Grundlage dafür bildet das Product Lifecycle Management (PLM). Innerhalb des PLM werden alle Prozesse des Produktlebenszyklus aufgenommen, standardisiert und in ein konsistentes Datenmodell übernommen (siehe Abb. 1). Durch das PLM soll mehr Transparenz und Effizienz der Prozesse geschaffen werden, was bereits eine erste Orientierung im Prozess- und Strukturablauf eines Unternehmens ermöglicht [lei08].

Anhand des PLM sowie der agilen Werte (siehe auch den Beitrag von Isenhardt et al.: „Agile Werte im Innovationsmanagement“) wurde im Rahmen des Projekts Smarte Innovation ein IT-basiertes Werkzeug entwickelt, welches Entscheidern innerhalb eines Unternehmens eine Hilfestellung bei der Identifizierung des eigenen Innovationspotenzials bietet. Ein Fallbeispiel für jeden Prozessschritt führt den Befragten mithilfe der Methode des Storytelling in die zu seinem Arbeitsfeld passenden Prozessschritte ein, im Anschluss wird er zu seiner ganz persönlichen Arbeitsrealität befragt. Die Auswertung erlaubt Rückschlüsse darauf, in welchen Prozessen Strukturen und Standards ihren Sinn verloren haben, Kommunikationsprobleme auftreten oder die Kundenbindung zu schwach gelebt wird. Hier spielen gelebte agile Konzepte eine Rolle, die bei der Aktivierung von Innovationstreibern helfen können.

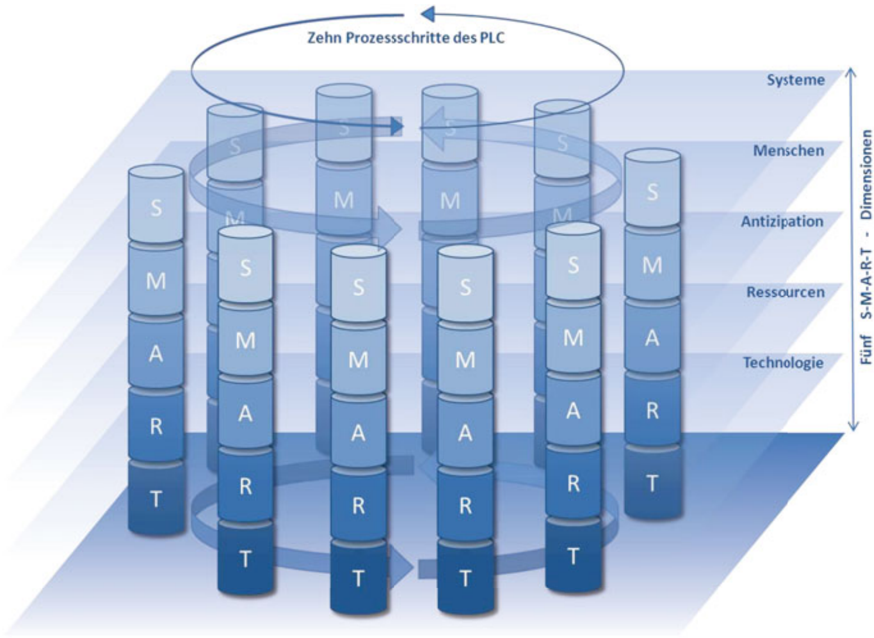

Abb. 2 Fünf S-M-A-R-T-Dimensionen vertikal zu den zehn Prozessschritten des PLM

2 Das IT-basierte Werkzeug zur Innovationsanalyse

Das neu entwickelte IT-basierte Werkzeug unterstützt Entscheider in Unternehmen dabei, ungenutzte Innovationspotenziale zu identifizieren, indem die eigene unternehmerische Realität reflektiert wird und Handlungsempfehlungen für eine agilere Prozessgestaltung gegeben werden. Auf Basis der durch das Institut für Sozialwissenschaftliche Forschung – ISF München durchgeführten Befragungen und Auswertungen von Innovationsworkshops wurden speziell für den Anlagen- und Maschinenbau Treiber und Hemmnisse ermittelt, die das Hervorbringen neuer Innovationen fördern bzw. hindern können. Hohe Motivation, eine geeignete Qualifikation der Mitarbeiter, eine rege, organisierte Kommunikation auch über die verschiedensten Prozessschritte hinweg – all dies können Stellgrößen für die Innovationsfähigkeit eines Unternehmens sein.

Das entwickelte IT-Werkzeug orientiert sich an den zehn Prozessschritten des PLM. Es ermöglicht die Analyse von Arbeitsrealitäten vor dem Hintergrund ihrer Relevanz für die Innovationskultur. In Zuordnung zu den einzelnen Prozessschritten des Produktlebenszyklus füllen Mitarbeiter des Unternehmens einen Fragebogen aus. Mittels einer Fallbeschreibung, die einen beispielhaften Vorgang im jeweiligen Prozessschritt anspricht, wird der Mitarbeiter in die Arbeitsrealität der Prozessphase eingestimmt. Die jeweiligen Fallbeschreibungen und Fragen adressieren die identifizierten Treiber und Hemmnisse für Innovationsfähigkeit in Unternehmen des Maschinen- und Anlagenbaus. Die Mitarbeiterbefragung orientiert sich hierbei nicht nur an den Prozessschritten des PLM, sondern zudem an den fünf S-M-A-R-T-Dimensionen (vgl. auch den Beitrag von Pfeiffer et al.: „Smarte Innovation – zur Einleitung"). In den einzelnen Frageblöcken adressieren die Fallbeispiele somit inhaltlich die Dimensionen „Systeme", „Menschen", „Antizipation", „Ressourcen" und „Technologie" und bilden dadurch einen aufgefächerten, breit aufgestellten Querschnitt über die verschiedenen Innovationstreiber und -hemmnisse (siehe Abb. 2). Danach werden diese auf die Prinzipien des agilen Handelns projiziert und abschließend werden Handlungsempfehlungen angeboten, die zur Aktivierung identifizierter Potenziale und somit zur Steigerung der Innovationsfähigkeit eines Unternehmens beitragen. Agile Prinzipien sind Regeln für die praktische Umsetzung agiler Werte und bilden die Basis der abgeleiteten Empfehlungen.

3 Anwendung und Durchführung der Innovationsanalyse

Das IT-basierte Werkzeug verfügt über zwei verschiedene Sichtweisen – die des Administrators und die der Mitarbeiter, die das Tool nutzen. Der administrative Bereich dient neben der Initiierung der Befragung und der dafür notwendigen Einrichtung von Mitarbeiterzugängen insbesondere der Auswertung der Ergebnisse der Innovationsanalyse (siehe Abb. 3).

Mitarbeiter, die über Einblicke in mehr als einen Prozessschritt des PLM verfügen, können für die Befragung zu mehreren Prozessschritten zugelassen werden. In der durch das Tool geführten Befragung können sich die Mitarbeiter zu Beginn ausführlich über die Methode und deren Nutzen informieren. Die Befragung ist so aufgebaut, dass die Mitarbeiter im jeweiligen Prozessschritt eine Mitarbeiterin oder einen Mitarbeiter des fiktiven Unternehmens „MANLAG GmbH" durch diesen Prozessschritt begleiten (siehe Abb. 4).

Anhand dieses beispielhaften Ausschnitts aus der Arbeitsrealität sollen die Befragten ihre eigene Realität verorten und den jeweiligen Prozessschritt auf ihre persönliche Arbeitssituation übertragen. Stephen Denning bezeichnet diese Art von Geschichten als sogenannte „Springboard Stories" [Den01]. Die Leser vollziehen dabei einen mentalen Sprung von der erzählten Geschichte zu einer ähnlichen Geschichte oder Situation ihres täglichen Lebens. Die modellierten Situationen bestehen immer aus einer kurzen Einführung und darauf aufbauenden Story-Abschnitten zu den fünf S-M-A-R-T-Dimensionen.

Abbildung 5 zeigt einen Screenshot aus der Mitarbeiterbefragung zum Prozessschritt „Produktentwicklung" im S-M-A-R-T-Abschnitt „Menschen". Die hier adressierte Frage zielt auf die Einbeziehung relevanter Personen in den Innovationsprozess. Ist der jeweilige Mitarbeiter nicht der Meinung, dass alle wichtigen Wissensträger in den Umsetzungsprozess involviert sind, so trägt an dieser Stelle der Umfrage eine negative Wertung zur Aufdeckung vorhandener, aber ungenutzter Innovationspotenziale bei. Das Einbeziehen insbesondere des letztendlichen Ideengebers oder eines späteren Anwenders bzw. Kunden in den Entwicklungsprozess ist für das Hervorbringen der eigentlichen Innovationen entscheidend.

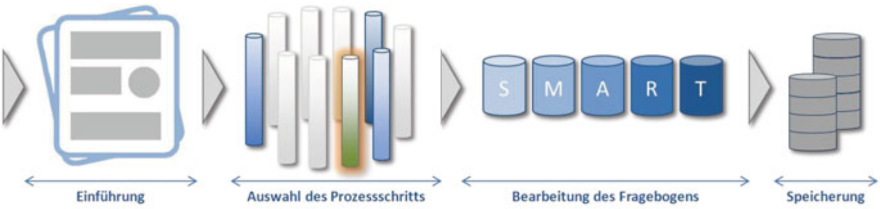

Abb. 3 Übersicht aller administrativen Vorgänge innerhalb des IT-basierten Werkzeugs

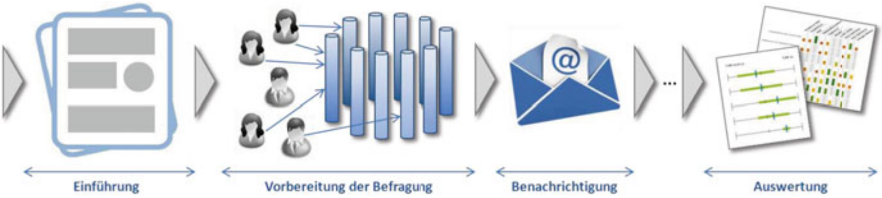

Abb. 4 Übersicht aller Vorgänge im Rahmen der IT-gestützten Mitarbeiterbefragung

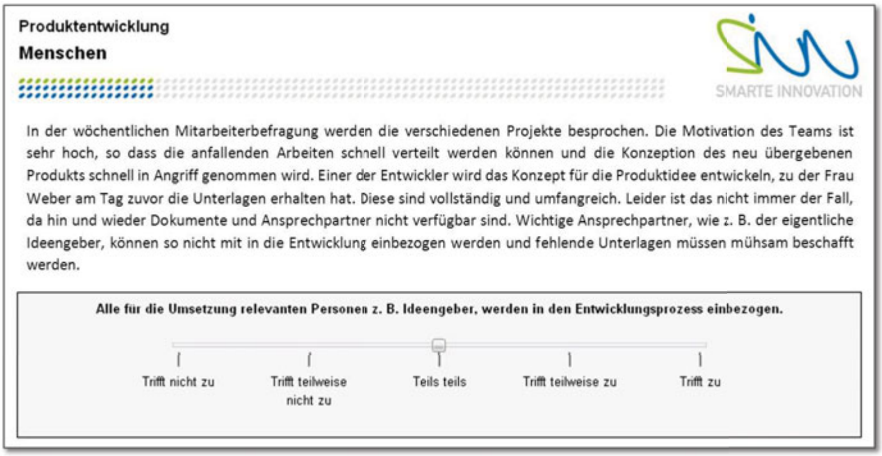

Abb. 5 Ein beispielhafter Screenshot aus der Befragung

Hieraus lassen sich möglicherweise Handlungsfelder ableiten, etwa im Sinn der Verbesserung der internen Kommunikation, der Anpassung von Organisationsstrukturen oder einer stärkeren Einbeziehung des Kunden in den Entwicklungsprozess, beispielsweise die Teilnahme des Kunden an regelmäßigen Projekttreffen.

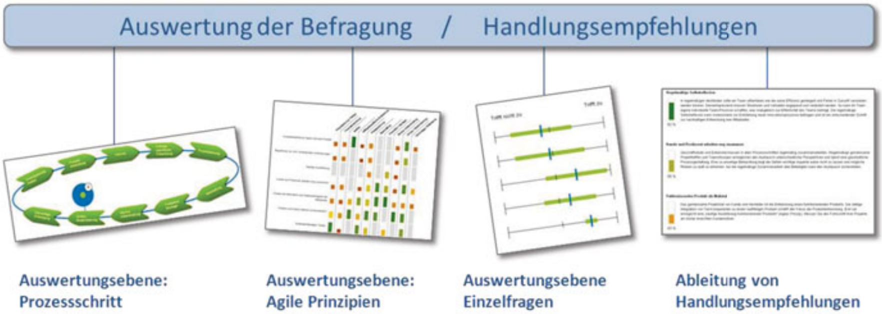

Abb. 6 Übersicht über die Analyseebenen

4 Auswertung der Befragung und Ableitung von Handlungsempfehlungen

Der Initiator der Mitarbeiterbefragung hat über die Auswertungsebene die Möglichkeit, die Ergebnisse der Befragung einzusehen. Für jeden Prozessschritt des PLM werden die Ergebnisse separat ausgewertet. In der Übersicht über alle Prozessschritte erfährt der Initiator, wie viele Personen bereits an der Befragung teilgenommen haben. In einer kreisförmigen Darstellung (siehe Abb. 6, Auswertungsebene: Prozessschritt) wird zudem ausgewertet, wie stark im jeweiligen Prozessschritt vorhandenes Innovationspotenzial genutzt wird. Der blaue Kreis stellt hierbei das vorhandene Innovationspotenzial dar, der innere grüne Kreis steht für die Nutzung des Potenzials. Je mehr Treiber von Innovation bei der Befragung im Prozessschritt identifiziert wurden, umso größer wird die Darstellung des grünen Kreises, bis sie den blauen Kreis vollständig abdeckt. Diese sehr vereinfachte Darstellung soll einen ersten Eindruck von der Befragung vermitteln.

Neben der allgemeinen Übersicht über alle Prozessschritte kann in einer weiteren Auswertungsebene das Ergebnis der Befragung für einen einzelnen Prozessschritt separat betrachtet werden. Jede für den Prozessschritt gestellte Frage wird hier mit Mittelwert und Standardabweichung aufgetragen (siehe Abb. 6, Auswertungsebene: Einzelfragen). So können auch sehr individuelle Problemstellungen identifiziert werden. Die Frageblöcke sind analog zur jeweiligen Springboard Story in die fünf S-M-A-R-T-Dimensionen gegliedert.

In einer Matrix wird schließlich aufgetragen, inwieweit die zwölf agilen Prinzipien innerhalb der zehn Prozessschritte gelebt werden (siehe Abb. 6, Auswertungsebene: Agile Prinzipien). Abbildung 7 verdeutlicht die Projektion der Innovationstreiber und -hemmnisse auf die zwölf agilen Prinzipien und deren Bedeutung für die Prozessschritte des Produktlebenszyklus.

Die nachfolgende Formalisierung beschreibt den konzeptionellen Unterbau und bildet die Basis für die Innovationsanalyse und die anschließende Ableitung von Handlungsempfehlungen.

Die in Abb. 7 dargestellte Matrix A und deren jeweilige Einträge a_{ij} sind wie folgt definiert:

$$A = \begin{pmatrix} a_{1,1} & \cdots & a_{1,n} \\ \vdots & \ddots & \vdots \\ a_{12,1} & \cdots & a_{12,n} \end{pmatrix} = (a_{ij}).$$

Die Gewichte a_{ij} beschreiben die Zusammenhänge zwischen dem i-ten agilen Prinzip und dem j-ten Treiber bzw. Hemmnis für Innovationsfähigkeit in numerischer Form.

Das Gewicht p_{jk} der Matrix P ist so definiert:

$$P = \begin{pmatrix} p_{1,1} & \cdots & p_{1,10} \\ \vdots & \ddots & \vdots \\ p_{n,1} & \cdots & p_{n,10} \end{pmatrix} = (p_{jk}).$$

Es beschreibt den Zusammenhang zwischen dem j-ten Treiber und Hemmnis und dem k-ten Prozessschritt des Product Lifecycle.

Analog zu P lassen sich die Mittelwerte aller Ergebnisse der durch die Innovationstreiber und Hemmnisse implizierten Mitarbeiterbefragung durch die Matrix E formalisieren:

$$E = \begin{pmatrix} e_{1,1} & \cdots & e_{1,10} \\ \vdots & \ddots & \vdots \\ e_{n,1} & \cdots & e_{n,10} \end{pmatrix} = (e_{jk}).$$

Ein Eintrag e_{jk} beschreibt somit den Mittelwert der Antworten aus Prozessschritt k auf die Frage zum Innovationstreiber bzw. -hemmnis j zwischen 0 („Trifft nicht zu“) und 100 („Trifft zu“). Existiert keine Frage zu Innovationstreiber j in Prozessschritt k, so gilt: $e_{jk} = p_{jk} = 0$.

Aus A, P und E lässt sich anschließend die Bewertungsmatrix B ableiten mit:

$$B = \begin{pmatrix} \frac{\sum_j a_{1,j} \cdot e_{j,1} \cdot p_{j,1}}{\sum_j a_{1,j} \cdot \sum_j p_{j,1}} & \cdots & \frac{\sum_j a_{1,j} \cdot e_{j,10} \cdot p_{j,10}}{\sum_j a_{1,j} \cdot \sum_j p_{j,10}} \\ \vdots & \ddots & \vdots \\ \frac{\sum_j a_{12,j} \cdot e_{j,1} \cdot p_{j,1}}{\sum_j a_{12,j} \cdot \sum_j p_{j,1}} & \cdots & \frac{\sum_j a_{12,j} \cdot e_{j,10} \cdot p_{j,10}}{\sum_j a_{12,j} \cdot \sum_j p_{j,10}} \end{pmatrix} = (b_{ik}).$$

Die angegebenen Quotienten dienen der Normalisierung der Bewertung auf einer Skala zwischen 0 und 100 Prozent. Ein Eintrag b_{ik} steht somit für die Bewertung, wie stark das agile Prinzip i in Prozessschritt k gelebt wird. Matrix B entspricht also der in Abb. 6 angedeuteten und grafisch aufbereiteten Auswertungsebene der agilen Prinzipien.

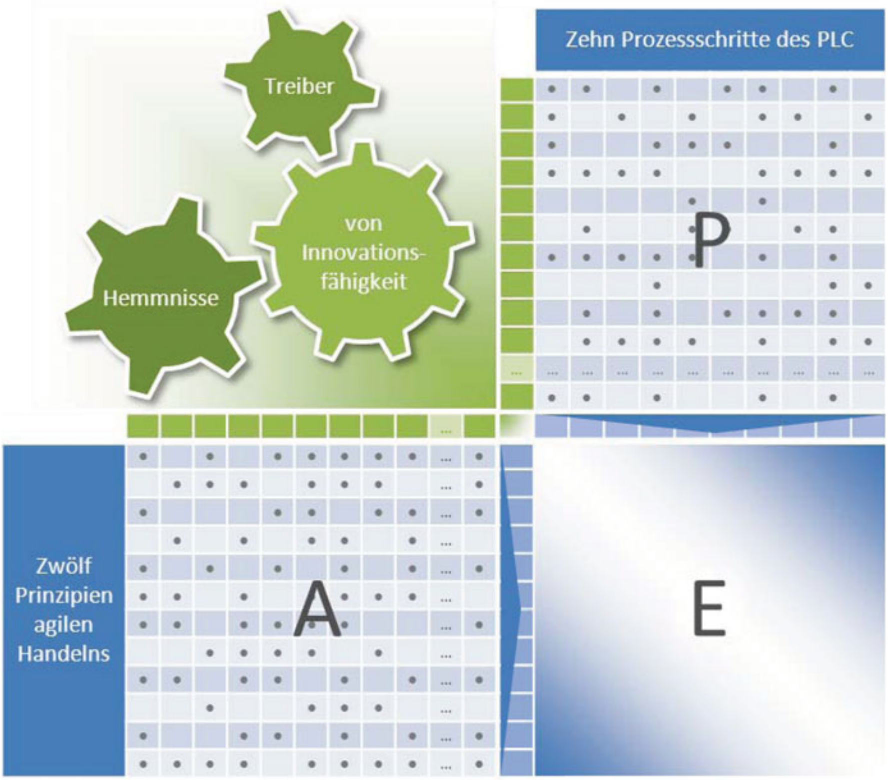

Abb. 7 Ableitung der Bewertungs-Matrix *B*

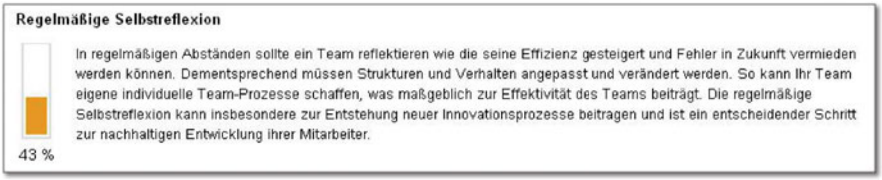

Abb. 8 Beispiel für eine Handlungsempfehlung zum agilen Prinzip „Regelmäßige Selbstreflexion“

Abbildung 8 zeigt einen Screenshot aus der Ebene: Ableitung von Handlungsempfehlungen. Die Mitarbeiterbefragung hat hier bei einem Prozessschritt ergeben, dass erhebliches Potenzial in der Durchführung regelmäßiger Selbstreflexionen liegt. Die angegebene prozentuale Darstellung entspricht der Bewertung $b_{12,1}$, da sie einer Auswertung für das zwölfte agile Prinzip im ersten Prozessschritt “Produktplanung und Design” entspricht. Basierend auf dieser Auswertung werden nun Handlungsempfehlungen angeboten, wie agile Prinzipien stärker in die Unternehmenskultur integriert werden können.

5 Technische Umsetzung

Für die technische Umsetzung des beschriebenen IT-basierten Werkzeugs wurden moderne Webtechnologien verwendet. Das IT-Werkzeug wurde in der Programmiersprache Java entwickelt und setzt auf einem Google Web Toolkit Framework (GWT) [HTA07] auf. Somit wird auf Seiten des Endnutzers lediglich ein internetfähiger PC mit einem Browser der neueren Generation vorausgesetzt. Auf Serverseite bilden ein Apache-Webserver sowie ein Tomcat-Application-Server [Sta10] die Kommunikation mit dem Endnutzer ab. Zur Speicherung der Befragungs- und Auswertungsergebnisse wurde eine herkömmliche MySQL-Datenbank eingesetzt. Durch die gewählte Technologie zur Umsetzung des Innovationstools ist eine einfache und problemlose Nutzung der Anwendung gewährleistet.

6 Zusammenfassung

In diesem Kapitel wurde ein IT-basiertes Werkzeug zur Innovationsanalyse vorgestellt, welches Stellgrößen für Innovationen entlang der zehn Stationen des PLM in den fünf S-M-A-R-T-Dimensionen „Systeme", „Menschen", „Antizipation", „Ressourcen" und „Technologie" identifiziert. Durch eine Projektion der agilen Prinzipien auf die Treiber und Hemmnisse von Innovationen wird bestimmt, inwiefern das „Leben" der agilen Prinzipien für die Aktivierung dieser Potenziale genutzt werden kann. Die durch das IT-basierte Werkzeug initiierte Mitarbeiterbefragung zielt im ersten Schritt auf die Identifikation von unternehmensspezifischen Innovationstreibern und -hemmnissen und projiziert diese in einem zweiten Schritt auf die zwölf Prinzipien agilen Handelns. Für die Implementierung agiler Konzepte zur Aktivierung der verborgenen Potenziale werden anschließend Handlungsempfehlungen abgeleitet. Das vorgestellte IT-basierte Werkzeug kann somit wichtige Hinweise zur Gestaltung von Innovationsprozessen geben und ist so wichtiger Bestandteil der innerbetrieblichen Selbstreflexion. Zudem werden Anregungen für eine agilere Gestaltung der Unternehmenskultur aufgezeigt.

Inhaltliche Grundlage waren neben den für den Anlagen- und Maschinenbau ermittelten Erfolgsfaktoren das Agile Manifest sowie agile Methodiken, wie beispielsweise Scrum [Pic07], Crystal [Coc05], Extreme Programming [Bec00] und weitere Instrumente des agilen Projektmanagements. Für die Ableitung von Handlungsempfehlungen wurden die agilen Werte und Prinzipien, deren Ursprünge in der Softwareentwicklung liegen, auf den Innovationsprozess im Anlagen- und Maschinenbau übertragen. Diese abgeleiteten Handlungsempfehlungen sollen und können den Prozess der Interpretation der Analyseergebnisse und die Ableitung individueller Handlungsszenarien anregen und flankieren. Zur erfolgreichen Anpassung und Übertragung der Empfehlungen auf die eigene Unternehmensrealität bedarf es der eingehenden Reflexion durch verschiedene Unternehmensebenen und -instanzen. Das vorgestellte IT-Tool – so haben erste Anwendungen gezeigt – unterstützt und beschleunigt diesen Prozess unter Einbindung der Mitarbeiter.

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Learning by Playing: Potential of Serious Games to Increase Intellectual Capital

Bodo von der Heiden, Verena Bock, Anja Richert, Sabina Jeschke

Abstract This article discusses the potential for the use of *serious games* by businesses. Firstly, it explores the world of digital learning games in general, then goes on to explain the frequently used yet somewhat vague term *serious games* and the gen-eral benefits to be gained from combining the two ostensibly *opposed* concepts of playing and learning. Finally, a particular discipline – the digital simulation game – is examined in more detail using a practical example.

Key words: Serious Games, Simulation Games, Learning and Playing, Computer Based Learning, Web Based Learning

1 Introduction to the Topic

Due to their increased inclusion in basic and further training and simulation, serious games have been a key subject of academic discourse for some years [EL08]. There is as yet no standardised definition of the term *serious games* which range from simple learning games to simulation games lasting up to several months and First Person Shooter[1] games used for training by the military [MC06]. Despite or even because of the broadness of the term *serious games*, their applications can be adapted to suit different companies. They provide an opportunity to boost a company's innovative capabilities and thus generate or increase competitiveness. This is particularly thanks to the fact that the use of serious games enhances a company's intellectual capital by improving the players'/employees' soft skills (*know-how*), which in turn increases the probability of economic success.

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[1] Games where the players assume the role of a human or human-like game character and fight other players or computer-controlled opponents with firearms in a virtual environment.

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2 Learning Games, Serious Games and Simulation Games

2.1 Playing and Learning

The prevailing learning culture of the German-speaking world tends to take a critical view of synthesising learning – a serious activity – and playing – an entertaining pursuit [MS03]. These two activities are polarised as far as possible (learning vs. entertainment), particularly in an academic context, as demonstrated among other things by the fact that computer-assisted learning concepts have up till now rarely been used in the classroom (Petko [Pet08] offers an overview of the potential of computer-assisted teaching). In academic discussions, however, it is apparent that playing and learning are not by any means opposites, that there is in fact a long tradition of combining the two [Bop06], and that playing holds an important place in the human learning process [Ves03].

In parallel with – and also because of – these insights, the social stereotypes that claim a causal link between an alleged loss of values among the youth and excessive use of computer games are gradually fading. In the age of Web 2.0, computer games have long since transcended the realm of children's bedrooms and living rooms, with the trend for computer-based learning games extending into corporate (basic and advanced) training, known as game-based learning [Bre09] or serious games [Zyd05].

The concept behind computer-based learning games is based on the idea that a close link between learning tools and digital play tools supports the acquisition and consolidation of knowledge and skills. This is achieved by transferring play-based learning processes to a computer-generated virtual environment. Unlike traditional, non-computer-assisted learning games, they use motivational methods from digital entertainment media – such as *para-social relationships* between players and NPCs (Non Personal Characters) [KV02] – in order to encourage the player to learn [Bop06, Bop07].

2.2 Overview of the Genre

2.2.1 The Term Serious Games

The term *serious games* was used at the end of the 1960s before the computer age by Clarc C. Abt, who discussed the use of non-digital games and simulations in education in his book *Serious Games, Abt. 1987*. This label now covers a broad spectrum of digital learning applications with play-based elements, and what exactly lies behind it is not always clear. In both German- and English-speaking countries, a whole range of terms are used in a similar way, such as game-based learning, digital learning games, computer learning games or educational games. In some

	CBT/WBT	Simulation game/ simulation	CBT/WBT with game elements	Quiz, Memory, Solitaire, etc.	Virtual learning env.	Adventure learning game	Other games
Visibility of learning objectives	Clearly defined learning objectives; didactically oriented structure	Clearly defined learning objectives; didactically oriented structure	Clearly defined learning objectives, attractive story & characters	Clearly defined task	Little pre-structured & discovery-based learning	Integration of game-play and didactics	Unperceived, unplanned learning (or "hidden curriculum")
Communicable content/ skills	Primarily knowledge-oriented content ("know that")	Primarily decision-making skills & systemic interrelationships ("know how", "know why")	Primarily decision-making skills & systemic interrelationships ("know how", "know why")	Recall/testing of what has been learnt ("know that")	Orientation behaviour; knowledge-oriented content ("know that"); decision-making skills ("know how")	Primarily knowledge-oriented content ("know that"); decision-making skills ("know how")	Primarily cognitive & sensomotoric skills; media skills
Motivation primarily through	Expected learning success; certificate	Expected learning success; role-play & curiosity; context/story	Expected learning success; context/story; game/fun elements	Direct feedback (success)	Curiosity; experiencing success in solving tasks; context & characters	Inherent momentum of the game; expected learning success	Inherent momentum of the game (fun, excitement)
Example	„MySQL für Einsteiger"	„TopSIM Logistics"	„Das Vermächtnis des Amun"	„KnowCar", „The Challenge"	„Mathica", „Addy-Serie"	„The Monkey Wrench Conspiracy"	„Tomb Raider"

Fig. 1 Types of learning games according to Meier and Seufert [MS03]

cases, these are used synonymously, but mostly the terms differ depending on the concepts on which they are based. Lampert, Schwinge et al. [LST09] offer a good overview of this.

Although the term *serious games* is becoming increasingly more established in literature, there is no standardised definition. Zyda [Zyd05] defines it as "a mental contest, played with a computer in accordance with specific rules that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives". The author distinguishes serious games from conventional computer games as follows: "[...] activities that educate or instruct, thereby imparting knowledge or skill. This addition makes games serious. Pedagogy must, however, be subordinate to story – the entertainment component comes first. Once it's worked out, the pedagogy follows." What pedagogic intentions are constituent in a particular game and how the learning environment is structured accordingly depends ultimately on various factors such as the learning objective, requirement and motivation of the target group. Over time, many different forms have therefore emerged within the genre of serious games.

2.2.2 Types of Serious Game

The typology of digital learning games by Meier and Seufert [MS03] (see Fig. 1) systematically classifies the different serious game formats.

Based on the pedagogic dimensions of interactive learning systems according to Reeves [Ree92], the authors assign each individual type a place between the two poles *objectivist* and *constructivist* (see Fig. 2).

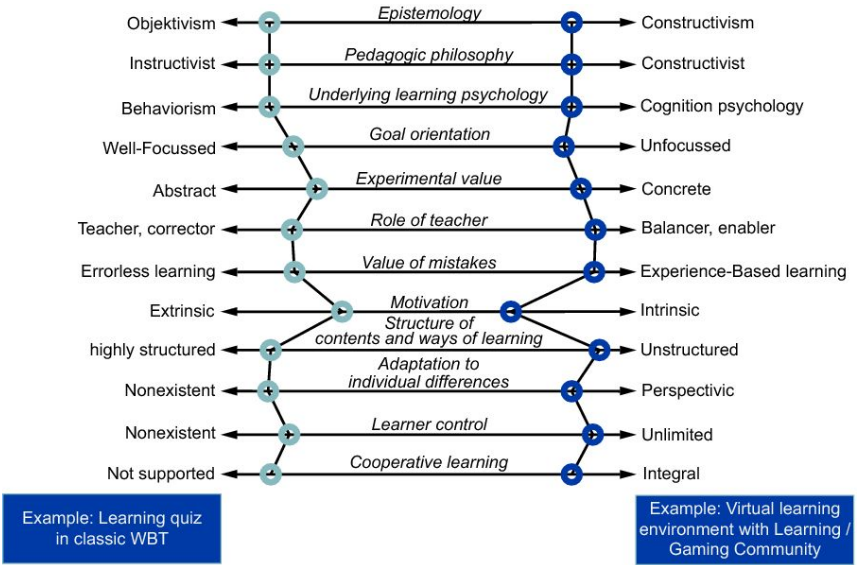

Fig. 2 Pedagogic dimensions of interactive learning systems according to [Ree92]

The categories *visibility of learning objectives, communicable content and skills* and *motivational impact* are used as features for distinguishing the individual types. The prototypical characteristics of the objectivist teaching concept are demonstrated by clearly defined learning objectives and highly structured learning content that make learning objectives clearly visible to the user. Emphasis is placed on conveying knowledge – *knowing that* – as opposed to constructivist concepts which also focus on the acquisition of decision-making skills, i.e. *knowing how*. Learning from experience through the player's interaction with learning objects is also a high priority in constructivist learning games. The learning objectives are therefore relatively unfocused. Games that are based on the latter concept offer the user the possibility of appropriating the content independently or in cooperation or interaction with a learning and game community. This carries with it an intrinsic motivation to learn, insofar as the player is rewarded by the inherent momentum or positive play experience, unlike objectivist learning games where the user is subject to external stimuli such as corrections through implemented feedback.

It should be mentioned at this point that, in addition to differentiating between serious games based on their didactic design, the literature also contains other typologies (e.g. Ritterfeld [Rit09]) which differentiate individual forms on the basis of other features such as the age of the target group or the level of training [BB10].

3 Simulation Games and Business Simulations

3.1 Classification and Overview

3.1.1 What Are Simulation Games?

Because the term serious games is very broad, as described in Sect. 2.2.1, this section takes a more detailed look at a particular type of serious game – the simulation game. This type of serious game was chosen because it is already used frequently in the Anglo-American world, but still has potential for more widespread use in German-speaking areas (Raffoul 2009).

Referred to by German speakers as *Planspiele* (literally *planning games*), the established terms for this concept in English are *gaming simulation* and *simulation game* – terms which leave no doubt as to the close link between these games and simulation. According to Henning and Strina [HS03], a definition of the term simulation game should above all stress the simulation aspect as a central feature and place less emphasis on the planning aspect. This aspect is explored by Ameln and Kramer [AK07], among others, in their definition of simulation games: "Simulation games are dynamic models for simulating a (business-management, economic, social and psychological) dynamic system with the aim of understanding, evaluating and shaping it more effectively" (translated by author). Though simulation is a central element of a simulation game, the two are not one and the same, as a pure simulation has no planning aspect [GM95]. The literature on this subject includes many further definitions of simulation games which are largely consistent and stress, for example, the simulative character as a key feature of simulation games [Geu00].

3.1.2 Differentiation Criteria and Applications of Simulation Games

In Germany, there are currently around 400–500 simulation games on the market which are – as Ameln and Kramer [AK07] rightly state – "as varied as the reality they attempt to represent" (translated by author). Ameln and Kramer [AK07] summarise the differentiation criteria and applications of simulation games on the basis of the classification scheme according to Blötz [Blö08] (see Fig. 3). They distinguish between: group vs. individual simulation games; company, job-oriented and industry simulation games; open vs. closed simulation games[2] and manual and computer-assisted simulation games.

It is important to note that the classification of the individual categories is prototypical. Many games exhibit characteristic features of several categories and therefore cannot be uniquely assigned to just one category in the classification grid. The boundaries are often fluid in practice.

[2] Closed simulation games are based on a problem and how the player wishes to solve it, while open simulation games are based on a situation and how to handle it.

Classification according to type of

Game medium	Model / frame of reference	Tutorial guidance	Social arrangements
PC-supported interactive learning games ✓	Corporate simulation games (gen.) ✓	Trainer-led simulation games ✓	Group simulation games in parallel operation ✓
Form-supported simulation games (✓)	Job-oriented simulation games ✓	Simulation games without trainers ✓	Group simulation games with competition (✓)
Interactive online games ✓	Industry simulation games ✓	Online tutorials (✓)	Individual simulation games ✓
Competition centre (electr.) ✓	Behaviour-based, role-based simulation game (✓)		Remote simulation game competitions ✓
Competition centre (conv.) (✓)	Free-form games (open) (✓)		
Board-based simulation games ✓			

Fig. 3 Types of simulation game according to [Blö08]

3.1.3 Advantages of Simulation Games

Eichhorn [Eic00] sums up the advantages of simulation games compared with classic approaches to learning as follows:

- Present complex and convoluted theories in a simplified model
- Equip the participants to convert their existing theoretical knowledge into practical skills.

Simulation games are particularly beneficial to learning "when the contexts learnt in the simulated reality can be transferred and applied to the learner's known environment or a subsequent application scenario (reality). [...] This mirroring is what makes the game experiences useful for the learner's own reality" ([Cap02], translated by author). Regarding the similarity between game and real scenarios, Kerres, Bormann et al. [KBV09] note that the following should be borne in mind: "In company simulation games, the simulation can only imitate the real system, as the design principles of this system are not known. Rules for successful company management can be plausibly formulated on the basis of models, but can scarcely be converted to functional equations that reliably represent e.g. real corporate developments" (translated by author). The situations experienced in the game are simplified representations of reality, but the gap is reduced in future developments, for instance by using computer-assisted Augmented Reality concepts. Whether and to what extent developments like this lead to further problems also depends on the extent to which the players are still able to distinguish between the real and the virtual.

3.2 The Benefits of Simulation Games for Companies

3.2.1 Role of Simulation Games in Establishing and Developing Professional Decision-Making Skills

The experiences required to make the right decisions in everyday work activities can only be acquired to a limited extent through theoretical input. As a rule, these skills are amassed through practical experience and routine work tasks, and mostly on the basis of knowledge gained as a result of correct or incorrect decisions. Simulation games can be particularly useful in this regard. They provide a risk-free space where users can try out diverse strategies for everyday work situations without having to suffer possible negative consequences which would entail action in reality, and receive direct feedback [Eic00, Bre09]. Simulation games help to improve the planning and decision-making behaviour of individuals and groups [HS03].

3.2.2 Increasing Intellectual Capital

Knowledge is a central production factor in our current and future knowledge- and information-driven society. Endogenous, i.e. internally driven, growth of knowledge is integral to this. Tomorrow's knowledge is generated from today's knowledge base and increases rapidly in scope. In order to keep pace with this development, the various social groups are forced to continuously update their (technical) knowledge. The structure of our knowledge society necessitates lifelong learning [MS03]. On the one hand, increasing employee fluctuation (for demographic and structural reasons), shorter lengths of stay [HK03] and the associated changes of employer put companies at risk of a knowledge drain, i.e. of their employees taking knowledge away with them when they leave. On the other, knowledge needs to be conveyed to new employees and their soft skills adapted to the needs of the company if necessary.

According to Brooking [Bro97], the term *intellectual capital* when referring to employees encompasses their (factual) knowledge, their skills, their work-relevant know-how and their ability to network. Serious games, in the form of special simulation games, allow new concepts for realising lifelong learning of knowledge and soft skills, because they enable existing knowledge to be distributed throughout the company and new knowledge to be integrated into the company, e.g. through observation of the simulation game process. They also provide the opportunity to communicate the *know how* to all employees.

3.2.3 A Look at the Learning Culture of the Next Generation

Having grown up in a digital world, the younger generation handles web technologies intuitively and with natural ease. Since the personnel development of the future will also include this generation, companies need to take this factor into account.

Prensky [Pre01] describes the younger generation as *Digital Natives* (singularity) as opposed to *Digital Immigrants* – today's generation of adults who, although they did not grow up in the digital world, are nonetheless able to tap into it. Veen and Vrakking [VV06] call this digital generation *Homo zappiens* and define it as follows: "This generation that we describe as Homo zappiens is the generation that has grown up using multiple technological devices from early childhood." Linked to this are new forms of speech, expression and communication, as well as new learning and thought structures which exhibit networked rather than linear characteristics. "Homo zappiens are active processors of information, skilled problem solvers using gaming strategies and effective communicators" [VV06]. Against this backdrop, the training sector is under growing pressure to find appropriate forms that cater to the requirements of this learning culture in new media. These include linking learning tools and computers, a challenge that companies will increasingly have to deal with in future. Alongside other e-learning formats, simulation games and simulations may offer a solution that allows both the next generation and the current generation of *Digital Immigrants* a suitable space to enhance their qualification profile with basic and further training and also ensures efficient knowledge transfer from one generation to the next when handing over to new staff.

4 A Practical Example – Simulation Game Portal for Large Groups

4.1 Introduction to Practical Example

Simulation games have demonstrated for centuries that they offer the means to activate "passive knowledge, i.e. knowledge that, though theoretically mastered, cannot be activated in a concrete application situation" ([SM03], translated by author). These games attempt to combine learning dry theory with enjoyable play [Hei92]. In the past, they were mostly board games such as chess and Go, probably the two best-known simulation games [Kna04]. Examples of simulation games that have been used successfully to date include *Q-Key,Haferkamp.2000*, *Micro-Key,Henning.2003*, *LogisticPLUS,Eichhorn.2000* und *Mastering Project Management,Meier.2003*. These demonstrated "that direct, real interaction of the game players is particularly effective in achieving key learning results which virtual interaction cannot replace" ([HS03], translated by author). Despite this assessment, an attempt was made to adapt these simulation games for web-based play. Like most conventional board-based simulation games, *Q-Key* and *Micro-Key* can only be played by relatively few people at any one time (5–10 players). This ensures personal contact among the players, while at the same time keeping the costs of implementing each individual round of the game the same.

The aim of this experiment is the "web-based implementation" of these games "for large-scale and cost-effective application (e.g. as part of university lectures)” ([Hei08], translated by author). Use in (large) companies is also planned in addition to university teaching. This result of successful implementation described by Högsdal [Hög01] as an *efficiency target* not only helps save costs while maintaining equally high learning success for the players and thereby increasing the intellectual capital (see Sect. 3.2.2), but also enables the application as part of a large event such as a university lecture or a large-scale further training programme within a company.

4.2 Q-Key and Micro-Key

The simulation game *Q-Key* was developed in order to increase the quality awareness of the employees of a company. The players learn that the quality of a product or a service is inseparably linked to this awareness. Using the simulation game allows the players to experience the networked interrelationships that produce quality within the company. Central to this is the awareness that the quality of a product also depends on cooperation between different departments (in a concrete scenario: Production, Sales/Shipping, Marketing/Service, Development/Construction and Acquisition). Each player assumes the role of a department other than the department in which he himself works [Haf00]. By adapting the names of the individual departments, the game can be set up to perfectly fit different companies.

Haferkamp [Haf00] describes in his dissertation the story of how *Q-Key* was developed and the principles behind it. He also describes in two case studies the extent to which its use by a model car manufacturer and a manufacturer of remote control systems for vehicles led to improvements in interdepartmental cooperation and the development of a shared quality image.

Micro-Key is a simulation game developed by Nußbaum [Nuß04], based on the work of Haferkamp [Haf00], to boost the decision-making skills of micro entrepreneurs.[3] Nußbaum [Nuß04] defined six learning objectives that deal with the way in which micro entrepreneurs can gather experiences through cooperation, be motivated to increase their skills through reflection of their own behaviour and be shown information and tips on organising work processes. These learning objectives are achieved by setting the micro entrepreneurs the task of organising a trade fair stand together. While each entrepreneur presents his own product on this stand, he is also shown how the services of the other companies can complement his own product. In the game itself, different players address the following tasks: coordination, writing talks, organising stand personnel, producing flyers, and stand equipment and design.

In both games, all players sit round a table (see Fig. 4) and throughout the duration of the game take responsibility for the department of a fictional company or

[3] Also very small businesses, mostly independent, that frequently provide knowledge-intensive services, have made a deliberate decision to be independent, wish to remain as very small businesses, do their own marketing and establish for themselves a supportive network of business relations [SNS02].

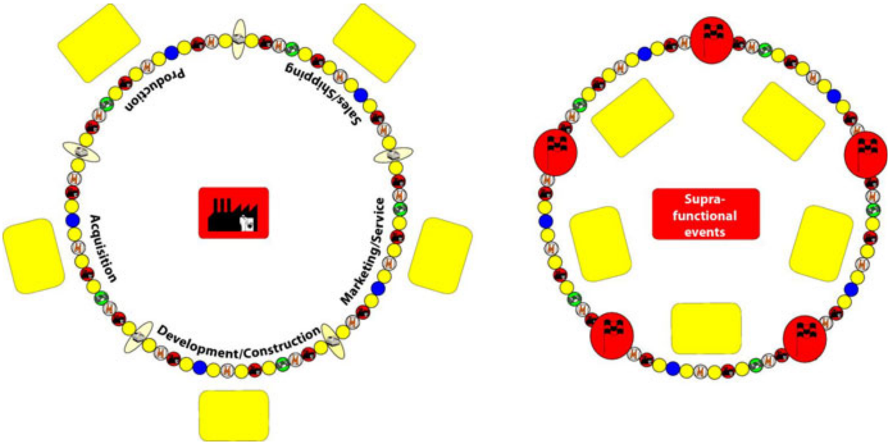

Fig. 4 Q-Key game plan (*left*), Micro-Key game plan (*right*)

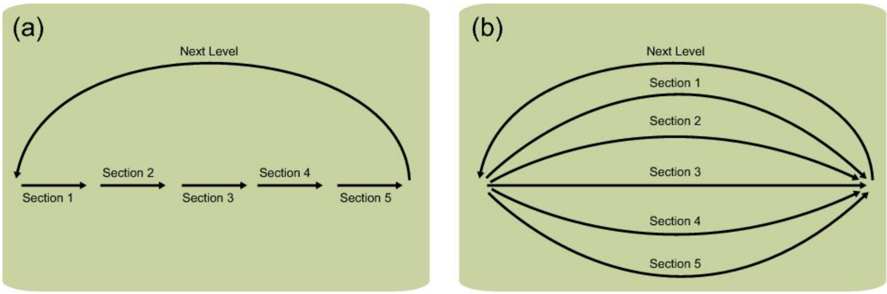

Fig. 5 **a** *Serial* play in the board-based version, **b** *parallel* play in the web-based version [Hei08]

micro enterprise. Players play in turn, and the individual actions of one player can have effects on the others. In both *Q-Key* and *Micro-Key*, players learn through their interactions and those of their fellow players.

4.3 Web-Based Implementation

Based on the knowledge that developing completely new simulation games is relatively expensive and that the concept behind *Q-Key* had also proved effective in the context of micro entrepreneurs (*Micro-Key*), a portal was developed for games with structures comparable to *Q-Key* and *Micro-Key* [Hei08]. A web-based version necessitates some changes to the game principle, such as the *parallelisation* of play, which had up till then been serial (see Fig. 5), changing the view of the play area (see Fig. 6) and introducing groups playing in parallel to create a competition situation.

Fig. 6 The simulation game portal – game view [Hei08]

The biggest problem with a web-based version, however, is the lack of face-to-face communication, as this is precisely what most of the learning success of the board-based version relies on. Based on Fischer [Fis06], the simulation game portal was therefore not developed purely as a web portal, but rather as a complement to an integrated learning concept that combines virtual learning modules with attendance events. Concepts such as forum, chat etc., for example, along with an award ceremony, are effective in boosting the integration of virtual and attendance segments while at the same time increasing learning motivation [Hei08].

There has not as yet been any detailed evaluation of the portal. Initial experiences show, however, that a system of incentives needs to be put in place, as the quality of learning drops for the individuals if all the participants do not jointly ensure this quality [Hei08].

5 Conclusion and Future Prospects

The aim of using serious games in a corporate context is to train a large number of employees to a high level. These games offer companies the opportunity to increase their intellectual capital (see Sect. 3.2.2) and make early preparations for future developments, such as a new generation of employees or a different knowledge structure within the company.

Although serious games and in particular simulation games are now being intensively studied, there is still a significant need for research in a number of areas. On the one hand, this centres around the question of the *portability* of existing, often successfully implemented board-based simulation games to web-based forms and the associated problems of adapting game concepts, as well as communication and awareness concepts. A further area where research is required is the question of evaluating the success (right up to certification) of further training based on serious games.

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Making Scientific Performance Measurable

Experiences from a German Cluster of Excellence

René Vossen, Florian Welter, Ingo Leisten, Anja Richert, Ingrid Isenhardt

Abstract New organizational forms of highly complex and interdisciplinary cooperation like clusters of excellence constitute a new challenge in terms of cluster management and controlling. With regard to the requirements for adequate means of operationalization and evaluation, conventional performance measurement approaches and indicators are not sufficient, because they focus mostly on monetary aspects. Within the cluster of excellence "Tailor-Made Fuels from Biomass" a performance measurement approach is implemented, focusing on quantitative as well as qualitative performance indicators. The approach bases on a Balanced Scorecard that is specified to the needs of interdisciplinary research cooperation. A mean of making various performance indicators measurable thus depicts a yearly survey among all hierarchical levels of cluster members to reflect the progress of the scientific output. The results are used as a basis of decision-making for the cluster management board. With regard to this, an operationalization and evaluation of performance indicators supports a continuous improvement process within the entire interdisciplinary cooperation. A further development of the measurement approach considers an integration of concepts like benchmarking and intellectual capital reporting to allow a more holistic form of scientific performance measurement.

Key words: Performance Measurement, Cluster of Excellence, Balanced Scorecard, Interdisciplinary Research Networks, Management of Supplementary Cluster Activities

1 Introduction

The cluster of excellence "Tailor-Made Fuels from Biomass" (TMFB) was established at RWTH Aachen University in 2007 in the context of the nationwide excellence initiative initiated by the federal government of Germany. The long-term

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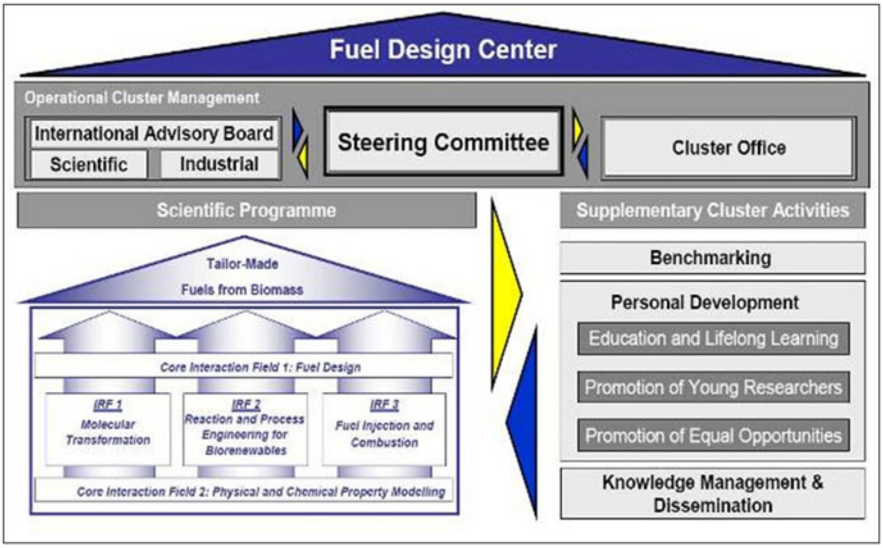

Fig. 1 The Fuel Design Center and the Structure of the Supplementary Cluster Activities (cluster of excellence "Tailor-Made Fuels from Biomass")

goal is to determine the optimal combination of fuel components and their production processes, which is based on renewable raw materials and new combustion processes [clu08]. The focus of TMFB lies on identifying innovative solutions for the customized conversion of the major components of plant material into value-added products, particularly for fuels and fuel components as the most important technologically and scientifically challenging application. Both conversions of biomaterial into tailor-made fuels, and the definition of optimal fuel properties, on the macroscopic level as well as on the molecular level, present a great challenge to chemo catalysis and bio catalysis, process technology, combustion research and engine development. The interdisciplinary nature of this approach, illustrated by bringing together e.g. chemists, biologists and engineers, is the key to a holistic and sustainable solution for future vehicular traffic, which is a basic necessity for a modern society [clu09].

The innovative, nationwide institutionalized form of interdisciplinary network cooperation requires an on-going control and management in order to adjust all members, projects and sub-projects to the superior aims and main ideas of the cluster of excellence. The Supplementary Cluster Activities (SCA) – coordinated by the IMA/ZLW & IfU of RWTH Aachen University – aim at the efficient networking of scientific processes within the cluster of excellence "Tailor-Made Fuels from Biomass". Tasks carried out by the SCA concern the implementation and analysis of ongoing measures in the field of strategy, controlling, scientific networking, education, lifelong learning and diversity management. Therefore, a conceptual framework has been developed to improve the cluster performance continually. Important aspects of the framework are the enhancement of the employees' satisfaction, efficient networking of the actors, as well as the initiation of learning processes within the cluster (see Fig. 1).

In terms of a cluster-specific continuous improvement process, this paper adopts the cluster-specific Balanced-Scorecard-approach, which measures and deeply reflects the cluster performance. Hence, selected results and performance indicators are presented.

2 Performance Measurement in a Cluster-Specific Context

Since the mid-eighties of the 20th century, the development of performance measurement systems has been intensified. Till this day they evolved into the epitome of a comparable measurement of organizational units. Moreover, globalization and increased competition on the world market have pushed the demand for quantification and raised the interest in the research area of performance measurement, as an approach to compare organizational output. The aim of the instruments is to increase the transparency of the pursued goals and to measure the act of achieving objectives, in order to be able to draw a conclusion about the effectiveness and efficiency of a process: "performance measurement can be defined as the process of quantifying the efficiency and effectiveness of action" [NMGP95]. Modern performance measurement systems such as the Quantum Performance Measurement System, the European Foundation of Quality Management-Modell or the Balanced Scorecard (BSC) [Töp00, Gle01, SP10] are able to evaluate soft qualitative control factors in addition to the conventional hard quantitative factors and thus expand the conventional form of monetary performance measurement. Whereas contemporary performance measurement systems are broadly implemented in the context of enterprises, the implementation of adequate performance measurement systems for scientific forms of organization like cluster of excellence is unexplored.

In order to design an adequate performance measurement system, the introduced terms have to be defined first. Our concept of an operational controlling approach contains the aspects of management and controlling, as well as regulation [Jan03]. A holistic management bases on controlling, which is able to measure the performance of all organizational units. This implicates an understanding of performance measurement as the measurement of efficiency and effectiveness of a whole organizational unit or a heterogeneous scientific network. Performance comes over as the ability to meet certain specifications by purposely changing the current status. The performance of an enterprise or scientific network is multidimensional, interdependent and incorporates strategic as well as operative aspects [Grü02]. An action is defined as effective when it causes a change in a condition to happen. Furthermore, it is efficient when the change which has already happened is not wasted [Ahn03]. A systematic oriented management process ensures that the total amount of results achieved within a scientific network meets the performance requirements and expectations of the research organization as defined above. In doing so it guarantees its competitiveness [Jet00]. Furthermore, performance measurement should be understood as a global approach, which considers the coordinated interaction of different methods and the achievements of the actors and teams involved. From the scientific network perspective, this leads to a permanent implementation of the maximum performance ability [Kli99]. A scientific cluster of excellence, as a specific cluster form, is characterized as a highly complex interdisciplinary research-based network, which initiates the processing of a common vision or a conceptual formulation in order to transfer them into sustainable structures. Regarding this, a scientific cluster of excellence unites scientific actors and – in dependence of its thematic focus – cooperations with the economy. The regional concentration of people, resources, ideas and infrastructure represents the cluster of excellence as a highly complex network with dynamic interactions challenging the design of knowledge processes. The basic assumption is that spatial proximity promotes the emergence of knowledge, innovations and excellent researchers as well as the economic development of the respective location [SSSH08, Ras09, dfg06, Höl06]. The performance measurement approach developed within the SCA meets the above defined requirements of a cluster-specific implementation and is described in the following sections.

3 Balanced Scorecard for Operationalization and Evaluation

Due to the fact that the cluster of excellence TMFB constitutes a scientific network characterized by scientific and organizational heterogeneity and publicly funded for a period of five years (from 2007 to 2012), an adequate performance measurement system is needed to control e.g. scientific output, personal development and the entire management strategy of the cluster. The implemented Balanced-Scorecard-approach in TMFB thus enables the measurement of performance indicators of the whole cluster. The Balanced Scorecard, developed in 1992 by Kaplan and Norton, constitutes a "performance measurement system" [KN92], primarily created as a communication-, information- and learning-system within enterprises. The Balanced-Scorecard-approach, which is implemented in TMFB and which is specified to the needs of the cluster, tries to transfer the theory from classical corporate controlling to the controlling of highly complex, knowledge intensive networks like the cluster of excellence. Due to the fact that the network of TMFB is characterized by a different form of organization and management than an enterprise, several modifications of the former BSC are necessary. Regarding the fact that cooperation within networks is based upon the voluntary decision of each agent to take part in the network, a special character of networks affects the network-specific organization of work [AC04, Sau05]. Hence, no strong hierarchical structures can be found within networks in contrast to the structures of conventional enterprises. Choosing the right way of decision-making depicts a challenge for the cluster management, because decision making cannot be done in a simple top-down manner. It rather needs to be conducted step by step through discussions with all actors of the network. Concerning the cluster of excellence TMFB, the willingness to lead a dialogue between the hierarchical layer of the cluster management, leading professors and leading researchers on the one side and the layer of PhDs and research assistants on the other side is crucial to build up trust for a successful development of interdisciplinary cooperations. To initiate a dialogue between these two layers within the cluster of excellence, the Balanced-Scorecard-approach is a promising tool, as it allows the definition of a common cluster vision, common targets and milestones [FS02]. In how far the vision and targets are fulfilled by all participants of the cluster can be examined by the implementation of a Balanced-Scorecard-based survey among all members of the cluster. The questions and corresponding figures of the survey are defined by the Supplementary Cluster Activities in co-operation with the cluster management. They can be compared and re-designed if necessary for the purpose of controlling after each annual survey. But how does the implemented Balanced-Scorecard-approach in TMFB look like?

First of all, it is necessary to define a common vision for the whole cluster which can be described as the development of ‘tailor-made fuels from biomass for a clean combustion’. This vision has to be communicated among all layers of actors in the cluster of excellence meaning that everybody has to adapt his or her scientific work to the defined common vision. Furthermore, the vision can be divided into several sub-targets and milestones helping to make the vision more operable and measurable for all participants of TMFB allowing a cluster-specific controlling. In contrast to the classical controlling approach which stresses the importance of hard (quantitative) performance indicators, a BSC tries to include soft (qualitative) performance indicators like the cluster-internal learning atmosphere or the development of cooperation among the researchers [FS05]. This is an important reason for the implementation of a Balanced-Scorecard-approach for the purpose of controlling within scientific networks which cannot be reduced to their financial output (see Fig. 2) [Ahn03].

According to the primary BSC of Kaplan and Norton, the modified Balanced-Scorecard-approach for TMFB possesses four perspectives which are necessary to create sub-targets [WVRI10]. The four perspectives are specified to the needs of the highly complex and dynamic research environment of TMFB. This explains the fact that they are not congruent with the perspectives named by Norton and Kaplan. One perspective of the cluster-specific approach Balanced-Scorecard-approach depicts the customer perspective/output including important sub-targets such as the need of the research results for the customer or society. Referring to the latter, also the economy can be defined as a customer who is interested in innovative scientific results of TMFB. Additionally, the generation of positive effects by the existence of the cluster of excellence on the research location of Aachen, e.g. the image of RWTH Aachen University, is defined as a sub-target and therefore it is a component of the Balanced-Scorecard-approach. Another perspective of the BSC in TMFB is constituted by the internal perspective/research cooperation. One of the aims of this perspective is the achievement of a strong and productive cooperation among the staff of the cluster. Facilitating direct and indirect communication between all actors in TMFB is a crucial sub-target in this perspective because a lack of scientific exchange within the cluster limits the development of interdisciplinary scientific results.

An exemplary sub-target of the learning and development perspective is the promotion of all employees in the network of TMFB – individuals as well as groups

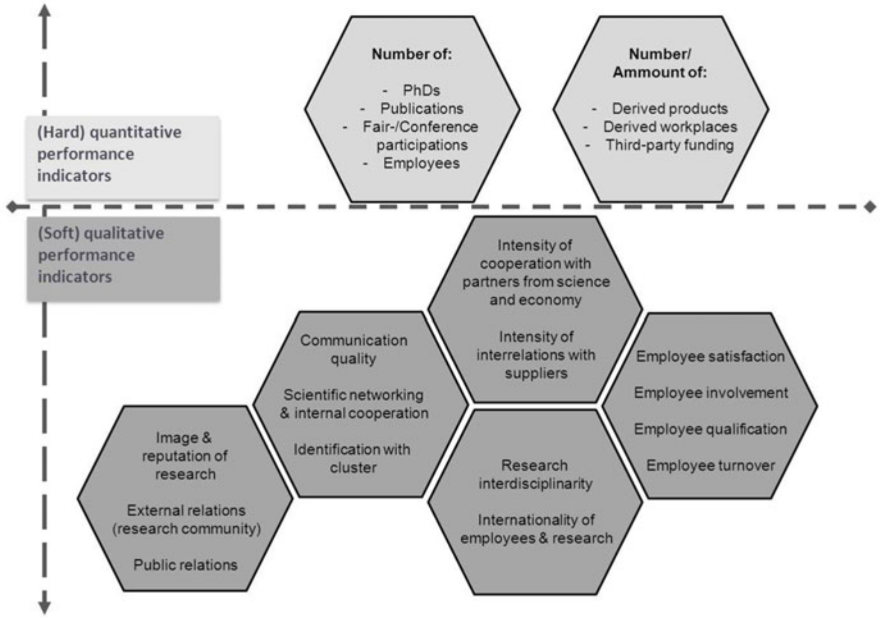

Fig. 2 Exemplary quantitative and qualitative performance indicators of the cluster of excellence "Tailor-Made Fuels from Biomass"

of scientists. Moreover, a common goal which has to be controlled regularly in order to adjust adequate steering measures depicts a high level of motivated scientists in the cluster of excellence. The financial perspective remains an integral part of the modified Balanced-Scorecard-approach. The focus within this perspective is set on questions concerning e.g. the working time of the researchers within TMFB. Selected questions of the four Balanced Scorecard perspectives are outlined in the following table (see Table 1).

The implementation of the Balanced-Scorecard-Approach in TMFB can be visualized by an iteration loop of different steps which is run through once a year (see Fig. 3).

With the intention to measure the performance of the network (step 1), the accomplishment of a web-based survey is a crucial part of the Balanced-Scorecard-based evaluation (step 2). Due to the fact, that the web-based survey is executed among the layer of the cluster management, leading professors and leading researchers as well as among the layer of PhDs and research assistants, comparable figures can be collected. Hence, an adequate statistical approach for the comparison of the figures depicts the calculation of average values and median throughout the scaled answers. The range of the scaled answers varies from 1 = 'positive answer' up to 5 = 'negative answer'. For the statistical analysis of data (step 3) these two layers are important to compare the corresponding answers of each group. In addition to the average values, the standard deviation of the respective answers has to be calcu-

Table 1 Selected questions of respective Balanced Scorecard perspectives

Selected questions of the Customer Perspective/Output	
	To what extent does this statement apply: The innovative abilities of producing companies can already be increased by the contemporary research results of the whole cluster of excellence.
	To what extent does this statement apply: The image of the research location of Aachen changed in a positive way through the cluster.
	How do you evaluate the publicity of the whole cluster of excellence (fair performances, presentations, brochures, yearly report, contacts to industrial partners)?
	To what extent does this statement apply: Through the synergies in the cluster of excellence more research output emerges than in 50 research projects of which each is financed with a full-time job.
Selected questions of the Internal Perspective/Research Cooperation	
	How do you evaluate the quality of existing scientific cooperation of the chairs and research facilities within the entire cluster and the sub-projects?
	How do you feel informed about the progress and results of the research work within the cluster of excellence?
	How do you evaluate the Knowledge Map as a networking tool for the cluster of excellence to share experiences, responsibilities, publications and main research activities?
	To what extent does the statement apply: The entire cluster-meetings and sub-project-meetings are helpful for my research.
Selected questions of the Learning and Development Perspective	
	How do you describe the general atmosphere in the cluster of excellence?
	How do you evaluate content and results of the yearly International Workshop in the cluster of excellence?
	How do you evaluate the entire scientific development of the cluster of excellence since the beginning of TMFB in 2007?
	To what extent are the contents and results of the entire cluster-meetings, sub-project-meetings and colloquia for assistants helpful concerning the transparency of decisions and results.
Selected questions of the Financial Perspective	
	To how many percent of your working time do you work in the cluster of excellence?
	To what extent does this statement apply: I grant my employees sufficient temporal free space so that they are able to fulfill their tasks within the cluster of excellence.
	To what extent does this statement apply: I receive sufficient temporal free space from my institute for the perception of my tasks within the cluster of excellence.
	To what extent does this statement apply: It is unproblematic that the scientific staff of the cluster works within different projects in TMFB or even outside TMFB.

lated, too, in order to analyze differences in the range of the given answers. Furthermore, qualitative remarks can be given by the participants so that not only figures are collected through the survey, but also qualitative answers or suggestions. Thereby, on the one hand differences among the answers of the two layers become obvious and on the other hand similarities and progress becomes clear [Jan03]. It seems obvious that a question, which is evaluated positively by both layers, is a worthwhile target, but especially the different evaluation of several answers displays a need for action for the cluster management. Because of this, the reflection of all answers

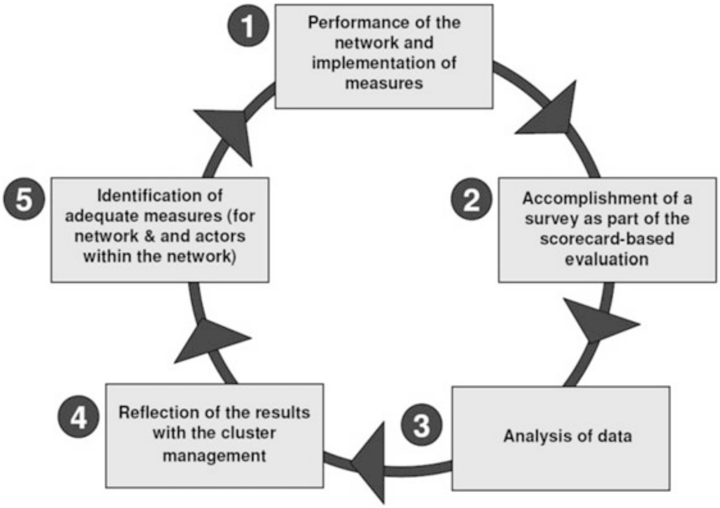

Fig. 3 Iteration Loop of the Balanced-Scorecard-approach

(step 4) is a significant task which is done by the representatives of the Supplementary Cluster Activities together with the executive board of TMFB. A continuous improvement process is initiated by reflecting the development of the whole cluster, which is described by Kaplan and Norton as "double-loop-learning" [KN01]. This means that the management reconsiders decisions made in the past in the context of actual circumstances. Furthermore, the identification of suitable measures, e.g. concerning the promotion of cooperation within the whole scientific network or single groups of the network, is an important step following the reflection (step 5).

With the implementation of the defined measures the iteration loop is completed and a new one can follow to measure the performance of the network again. The accomplishment of the iteration loops within TMFB is planned every twelve months meaning that four loops will be accomplished during the whole project period of five years (first evaluation in 2009, last evaluation in 2012). The possibility to compare the development of the answers over nearly the whole project period constitutes a crucial advantage in order to promote the quality of interdisciplinary cooperation continuously.

4 Selected Results

Results of the Balanced-Scorecard-approach in the cluster of excellence revealed a need of action in several sections. To further augment the quality of research processes and scientific output, the following aspects have been initiated:

- Performance indicators of the first evaluations in 2009 and 2010 made obvious that the cluster was initially lacking a transparent cascaded target system enabling all researchers to classify their respective sub-project into a common structure. Hence, a super-ordinated process picture providing detailed orientation in the highly-complex research processes of TMFB has been elaborated. An overall draft was communicated top-down by the cluster management board and expanded and filled by all researchers of the cluster in a following colloquium for research assistants. In doing so, a synchronization of scientific targets and interdependencies of single sub-projects has been achieved.
- Moreover, with the implementation of the colloquium for research assistants the management followed the results of the Balanced Scorecard based evaluation to support the transparency of cluster-wide decisions on the one hand. On the other hand, the colloquium was helpful to augment the quality of cooperations on the level of the entire cluster instead of the quality of cooperations on the level of single sub-projects.
- The evaluation of the cluster-specific publicity on the level of research assistants revealed further potential for improvement. Because of this the development of an image brochure 'TMFB – Through women's eyes' was promoted as an exemplary measure. Parallel to that the brochure promoted the gender and diversity activities of the cluster. The brochure underlines the diversity of the interdisciplinary and intercultural scientific co-operations in the cluster by presenting individual career paths and research focus of female TMFB scientists. It points out the attractiveness and multidisciplinarity of the cluster of excellence to young, talented and ambitious female students and researchers in order to engage their interest and enthusiasm about the important issue of "Tailor-Made Fuels from Biomass". By this means the internal and external knowledge transfer has been strengthened.
- The evaluation showed the need for an adaption and expansion of the cluster-internal knowledge map, as a semantic-based tool for digitally interlinking different scientific actors. Hence, in light of a scientific cluster of excellence a tracking tool for publications has been implemented to amend the digital form of exchange and cooperation. Through a graphical redesign of the entire tool the map layout is optimized for larger screen resolutions, to improve the usability and bridges the gap between user and administrative interface. The former now offers several shortcuts to administrative tasks like adding, editing or connecting objects. Furthermore, the index structure, which just listed all available objects, was changed into a map-like exploring tool that allows the user to keep track of the knowledge map. Besides these graphical modifications the underlying data model was partly refactored. The user management of the Knowledge Map was combined with the management of the objects representing each person. By this measure, the knowledge map now allows a detailed internal overview of the available knowledge and its distribution.
- To enhance the quality of scientific output the feedback of the evaluation was used, to design a tailor-made one-year advanced training program for PhD students of the research school "BrenaRo" (fuel production from renewable re-

sources) and the cluster of excellence TMBF. Against the backdrop of the SCA task lifelong learning, the program covers topics like academic writing, scientific working, presentation techniques, effective teamwork, project management and the training of rhetorical skills.
- Following further results of the performance indicators, a re-design of the yearly 'TMFB – International Workshop' has been achieved, integrating a technology-watch day for interested participants to foster knowledge transfer activities. Parallel to that the involvement of industrial partners into the International Workshop has been fostered to meet the demands of the TMFB members for a stronger exchange with this group of actors.

Regarding the results of the first two evaluations in the cluster of excellence TMFB one can conclude that the operationalization and evaluation of performance indicators by means of a cluster-specific Balanced-Scorecard-approach support a steering of the highly complex scientific cooperations, because the approach provides a basis for decision-making on the management level. By the reflection and analysis of the collected performance indicators through yearly iteration loops, cluster-internal learning processes have been initiated leading to a continuous improvement of diverse cluster-specific aspects as described in the selected results. In the research environment of a cluster of excellence performance measurement thus supports a critical analysis and discussion of scientific processes augmenting the quality of the scientific output.

5 Outlook

In future, a further re-design of the Balanced-Scorecard-approach will aim at integrating selected cluster-external stakeholders into the evaluation of performance indicators to strengthen the cluster-external view of the performance indicators. The renewed approach will also include indicators used for benchmarking with other cluster typologies and research networks. Concerning the latter, accompanying empirical research will further be accomplished by IMA/ZLW & IfU at RWTH Aachen University to identify and compare a catalogue of key performance indicators for scientific performance measurement. Apart from that, the examination and development of lean methods to analyze quantity and growth of the intellectual capital of the cluster of excellence will complement this field of action due to the emergent research field of intellectual capital reporting in the context of new public management.

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Der Exzellenzcluster „Integrative Produktionstechnik für Hochlohnländer“ an der RWTH Aachen
Management und Controlling von Interdisziplinarität

Florian Welter, Claudia Jooß, Anja Richert, Sabina Jeschke

Zusammenfassung Der Exzellenzcluster Integrative Produktionsttechnik für Hochlohnländer wurde im Jahr 2006 an der Rheinisch-Westfälischen Technischen Hochschule (RWTH) Aachen als Bestandteil der bundesweiten Exzellenzinitiative gegründet. Die bundesweit neuartige institutionalisierte Form von interdisziplinärer Forschung in einem Exzellenzcluster benötigt eine kontinuierliche Steuerung, um alle Clusterakteure und Teilprojekte auf das übergeordnete Ziel hin auszurichten. Untersuchungsgegenstand des vorliegenden Beitrags sind die Rahmenbedingungen, die die Zusammenarbeit in einem hochkomplexen, heterogenen Forschungs- und Entwicklungsnetzwerk prägen, die Herausforderungen hinsichtlich des Managements des Exzellenzclusters und der Mehrwert den ein Exzellenzcluster im Vergleich zu konventionellen Forschungsverbünden implizieren kann. Diesbezüglich wird herausgestellt wie mithilfe der „Cross Sectional Processes“, u. a. in Form von Strategieworkshops auf der Führungsebene sowie der Durchführung von Balanced-Scorecard-Evaluationen eine fortlaufende Selbstreflexion der Arbeit im Exzellenzcluster erreicht werden kann, um bei Bedarf steuernd eingreifen zu können.

Schlüsselwörter: Exzellenzcluster, Management, Controlling, Interdisziplinarität

1 Einleitung

Im Rahmen der bundesweiten Exzellenzinitiative wurde im Jahr 2006 der Exzellenzcluster Integrative Produktionstechnik für Hochlohnländer an der Rheinisch-Westfälischen Technischen Hochschule (RWTH) Aachen gegründet. Die übergeordnete Zielsetzung des Exzellenzclusters liegt dabei in der Steigerung der Wettbewerbsfähigkeit von Hochlohnländern und ihrer produzierenden Unternehmen. Um

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diese Zielsetzung zu erfüllen, werden integrative Ansätze für eine zukunftsfähige Produktionstechnik wie auch neue Methoden der interdisziplinären Arbeitsorganisation erforscht. Langfristig wird auf diese Weise angestrebt, das Polylemma der Produktionstechnik zu lösen, das aus den zwei Dichotomien scale vs. scope, und Planungsorientierung vs. Wertorientierung besteht.

Die bundesweit neuartige institutionalisierte Form von interdisziplinärer Forschung in einem Exzellenzcluster benötigt dabei eine kontinuierliche Steuerung, um alle Akteure und Teilprojekte auf das übergeordnete Ziel hin auszurichten. Untersuchungsgegenstand des vorliegenden Beitrags sind die Rahmenbedingungen, die die Zusammenarbeit in einem hochkomplexen, heterogenen Forschungs- und Entwicklungsnetzwerk prägen, die Herausforderungen hinsichtlich des Managements des Exzellenzclusters und der Mehrwert den ein Exzellenzcluster im Vergleich zu konventionellen Forschungsverbünden implizieren kann. Diesbezüglich wird herausgestellt wie mithilfe der „Cross Sectional Processes", u. a. in Form von Strategieworkshops auf der Führungsebene, der Ausrichtung von Mitarbeiterkolloquien, der Duchführung von Balanced-Scorecard-Evaluationen sowie Equal-Opportunities- und Diversity-Management-Maßnahmen eine fortlaufende Selbstreflexion der Arbeit im Exzellenzcluster erreicht werden kann.

Nach der Einführung in die Konzeption des Exzellenzclusters Integrative Produktionstechnik für Hochlohnländer und der Cross Sectional Processes wird der Beitrag auf Ergebnisse des Balanced-Scorecard-Ansatzes eingehen, mit dem die Performance des Netzwerks jährlich gemessen und reflektiert wird, um gegebenenfalls steuernd eingreifen zu können.

2 Hintergrund und übergeordnete Zielstellung des Exzellenzclusters

Aufgrund des wachsenden globalen Wettbewerbsdrucks, der in erster Linie seitens der aufstrebenden asiatischen Schwellen- und Industrieländer mit ihren relativ niedrigen Löhnen ausgeübt wird, gerät die produzierende Industrie der Hochlohnländer[1] zunehmend unter Zugzwang. Dabei ist sowohl im Hinblick auf Outsourcing einzelner Produktionszweige als auch im Hinblick auf Verlagerungen kompletter Produktions- und F&E-Aktivitäten in die Niedriglohnländer dringender Handlungsbedarf für die Hochlohnländer geboten [Bre08]. Die Tatsache, dass allein in Deutschland, nach einer Untersuchung des Deutschen Industrie- und Handelskammertags (DIHK) im Jahr 2005, bereits 23 % der Unternehmen eine Produktionsverlagerung planten, unterstreicht den Ernst der Situation [Bre08]. Unter diesen Voraussetzungen nimmt die Erzielung von Produkt- wie auch von Prozessinnovationen zur Aufrechterhaltung und Erlangung von Wettbewerbsvorteilen produzierender Unternehmen in Hochlohnländern eine immer wichtigere Rolle ein, da der

[1] Unter den Hochlohnländern, die in der produzierenden Industrie als weltweit führend einzustufen sind, befinden sich in erster Linie die etablierten westlichen Industriestaaten Nordamerikas und Europas sowie Japan.

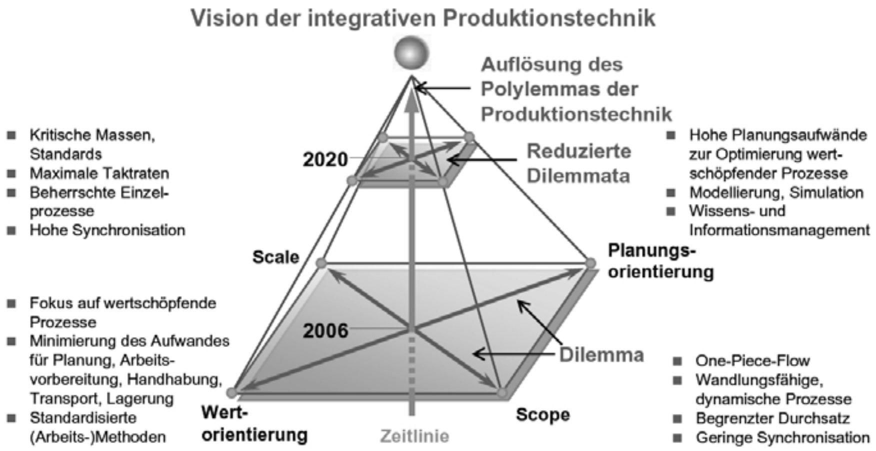

Abb. 1 Das Polylemma der Produktionstechnik [Exz07]

Innovationsdruck aus Niedriglohnländern steigt. Während den vergangenen Jahren hat sich in Wissenschaft und Wirtschaft die Erkenntnis durchgesetzt, dass Innovationen in erster Linie aus interdisziplinären Kooperationen zwischen fachlich heterogenen Partnern aus Wissenschaft und Wirtschaft resultieren. Diese Tatsache hat zu einer verbreiteten Implementierung von Clusterkonzepten und Netzwerken ähnlichen Typs beigetragen. So verfolgt auch

> der Exzellenzcluster „Integrative Produktionstechnik für Hochlohnländer“ an der RWTH Aachen [. . .] das Ziel, ausgehend von neuen Konzepten für die Produktionstechnik dem Abwanderungstrend wertschöpfender Produktionsprozesse entgegenzuwirken, so dass westliche Hochlohnländer wieder eine aktive Wettbewerbsrolle einnehmen. Auf den Stärken dieser Produktionsstandorte aufbauend, werden Ansätze verschiedener Wissenschaftsdisziplinen in ein ganzheitliches Konzept integriert, das neuen globalen Wettbewerbsstrukturen gerecht wird und zur Stärkung der Innovationskraft und Wettbewerbsfähigkeit der Hochlohnländer beitragen soll [Bre08].

Mit der Bewilligung des betrachteten Exzellenzclusters im Jahr 2006 wurden für diese Zielstellung Fördermittel in Höhe von rund 39 Mio. € seitens der Deutschen Forschungsgemeinschaft (DFG) und des Wissenschaftsrats (WR) zur Verfügung gestellt, die für die erste fünfjährige Förderperiode genutzt werden [Exz07][2]. Die übergeordnete clusterweite Vision stellt die Auflösung des Polylemmas der Produktionstechnik dar (siehe Abb. 1), welches aus den zwei Dichotomien scale vs. scope und Planungsorientierung vs. Wertorientierung besteht.

Ziel ist, die zukünftige Produktionstechnik der Hochlohnländer auf der einen Seite in die Lage zu versetzen, sowohl Vorteile der Massenproduktion durch die Erzielung von Skaleneffekten (economies of scale) zu realisieren als auch Vorteile kundenindividueller Produktion (economies of scope) nutzen zu können [Exz07].

[2] Deutschlandweit werden in der ersten Förderperiode (2006/2007 bis 2012) insgesamt 37 Exzellenzcluster gefördert.

Da Niedriglohnländer ihre derzeitigen Produktionsvorteile derzeit noch mehrheitlich durch die Fokussierung auf Massenproduktion erzielen, besteht für Hochlohnländer das strategische Interesse, durch eine Positionierung zwischen scale und scope Wettbewerbsvorteile zu erzielen. Auf der anderen Seite sind Hochlohnländer jedoch auch gefordert, sich mit der Dichotomie aus Planungsorientierung und Wertorientierung auseinandersetzen. Niedriglohnländer erzielen gegenwärtig Kostenvorteile durch den Einsatz einfacher, robuster wertstromorientierter Prozessketten. Damit stehen sie im Gegensatz zu den Hochlohnländern, die verbreitet eine kontinuierliche Prozessoptimierung mittels kapitalintensiver Planungsinstrumente verfolgen [Exz07]. Die Erzielung qualitativ hochwertiger Ergebnisse bei einer gleichzeitigen Reduktion des Planungsaufwands stellt somit für die Hochlohnländer die zukünftige Herausforderung dar, um sich gegenüber den Niedriglohnländern besser zu positionieren [Exz07].

2.1 Akteure im interdisziplinären Netzwerk des Exzellenzclusters

Die Akteure, welche auf die übergeordnete Zielstellung des heterogenen Netzwerks hinarbeiten, lassen sich in verschiedene Gruppen einteilen, die mehrheitlich einen wissenschaftlichen Hintergrund besitzen, teilweise jedoch auch durch einen wirtschaftlichen Hintergrund charakterisiert sind. Die größte Akteursgruppe wird dabei von den wissenschaftlich ausgerichteten Vertretern, in Form von Hochschulinstituten, Lehrstühlen, An-Instituten, Institutionen der Fraunhofer Gesellschaft und sonstigen F&E-Einrichtungen gestellt. 19 Lehrstühle mit dem fachlichen Schwerpunkt der Produktionstechnik und der Werkstoffwissenschaften wie auch 7 An-Institute der RWTH Aachen bilden die wissenschaftliche Basis des Exzellenzclusters [RWT06]. Weitere wissenschaftlich ausgerichtete Akteure, darunter hochschulnahe Kompetenzzentren und Foren, die ihren Sitz in Aachen haben, treten zudem als Kooperationspartner im Netzwerk auf. Auch internationale Forschungspartner nehmen am Exzellenzcluster teil (Kooperationspartner sind beispielsweise das Fraunhofer Center for Laser Technology (CLT) aus Plymouth/USA, das Fraunhofer Center for Manufacturing Innovation (CMI) aus Boston/USA, das Cranfield Innovative Manufacturing Research Centre (IMRC) aus Cranfield/Vereinigtes Königreich, die University of Leoben, Department of Metallurgy aus Leoben, Österreich). Im Gegensatz zu diesen internationalen Forschungspartnern unterscheiden sich weitere Kooperationspartner sowohl durch ihre Anzahl als auch durch ihre geographische Konzentration: Alle der gegenwärtig 17 Industriepartner, die bis auf wenige mittlere Unternehmen durchweg Großunternehmen bzw. Konzerne aus dem Bereich der Produktionstechnik und der Werkstoffwissenschaften darstellen, weisen dabei ihren Unternehmenssitz in Deutschland auf. Daraus folgt, dass – im Vergleich zu den wissenschaftlich ausgerichteten Akteuren – die räumliche Distanz der Industriepartner zur Sprecherhochschule des Exzellenzclusters, der RWTH Aachen, mehrheitlich relativ groß ist[3]. Im Hinblick auf die Beschäftigtenzahlen der wirtschaftlich orientierten Akteure liegt der arithmetische Mittelwert bei 73.194 Beschäftigten, der Median liegt bei 22.570 Beschäftigten. Die Differenz ist durch das Auftreten mehrerer Konzerne unter den Projektpartnern zu begründen, die mit ihren hohen Beschäftigtenzahlen den Mittelwert deutlich erhöhen. Die Spannweite der Beschäftigtenzahlen reicht von 125 Mitarbeitern bis über 400.000 Mitarbeiter, was die Heterogenität dieser Akteursgruppe hervorhebt. Die enge Verbundenheit des Exzellenzclusters Integrative Produktionstechnik für Hochlohnländer mit der Wirtschaft wird dadurch unterstrichen, dass seitens der Geschäftsführung das Ziel verfolgt wird, die wissenschaftlichen Erkenntnisse der einzelnen Teilprojekte im Exzellenzcluster in Zusammenarbeit mit Industrieunternehmen auf einen konkreten industriellen Anwendungsfall zu überführen (so genannte Business- & Technology-Cases).

Zusätzlich zur Einbindung von industriellen Partnern in bi- und multilaterale Teilrojekte des Exzellenzclusters nehmen auch Vertreter der Wirtschaft, durch ihre Teilnahme am Advisory Board, eine beratende Funktion ein [Exz07]. Anhand der

> Definition relevanter Themen aus der Industrie, [der] Beratung der Leitung des Exzellenzclusters hinsichtlich der inhaltlichen Ausgestaltung des Exzellenzclusters [und der] Bewertung der Forschungsarbeiten im Exzellenzcluster aus Sicht der produzierenden Industrie [Exz07]

werden auf diese Weise 19 beratende Akteure aus der Wirtschaft in das interdisziplinäre Netzwerk integriert, um Inhalte und Ziele des Exzellenzclusters zu hinterfragen.

2.2 Cross Sectional Processes im Aachen House of Integrative Production

Um den integrativen Ansatz des Exzellenzclusters zu verdeutlichen, wurde die in Abb. 2 dargestellte Organisationsstruktur des *Aachen House of Integrative Production* entwickelt. Dieses bildet die Aufgaben und Verknüpfungen der sechs sogenannten *Integrative Cluster Domains (ICDs)* ab. Durch diese Struktur wird verdeutlicht, dass die vier Säulen *Individualisierte Produktion (ICD A)*, *Virtuelle Produktionssysteme (ICD B), Hybride Produktionssysteme (ICD C)* und *Selbstoptimierende Produktionssysteme (ICD D)* von zwei weiteren Säulen, den Querschnittsbereichen *Technology Roadmaps (ICD E)* und *Cross Sectional Processes (ICD F)* umfasst werden. Hierdurch wird hervorgehoben, dass die beiden letztgenannten ICDs explizit eine ICD-übergreifende Funktion einnehmen und der Geschäftsführung des Exzellenzclusters unmittelbar unterstellt sind.[4]

[3] Hierbei bleibt zu erwähnen, dass die am Exzellenzcluster beteiligten 19 Lehrstühle nicht in einem gemeinsamen Gebäude verortet sind, sondern sich über das Gebiet der Wissenschaftsstadt Aachen erstrecken.

[4] Für eine ausführliche Erläuterung aller einzelnen ICDs, die nicht Bestandteil dieses Beitrags sein soll, sei beispielhaft auf das Werk von [SKBS07] sowie die offizielle Homepage des *Exzellenzclusters Integrative Produktionstechnik für Hochlohnländer* verwiesen (http://www.production-research.de).

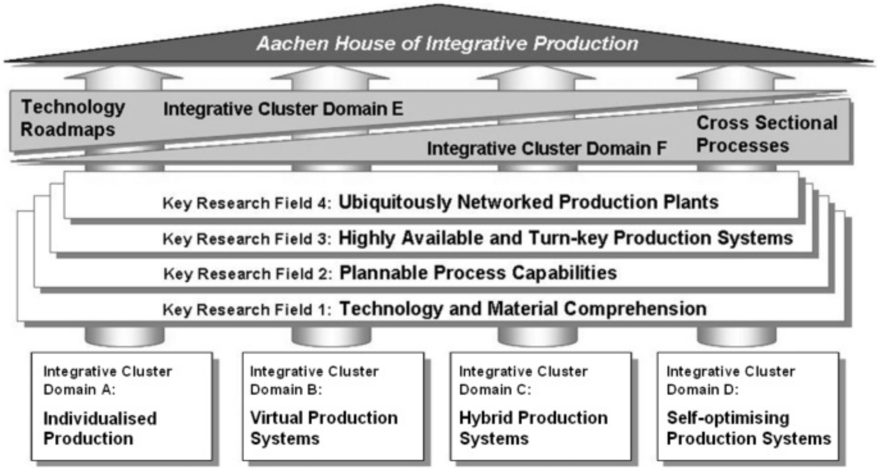

Abb. 2 Aachen House of Integrative Production [Exz07]

Als eine übergeordnete ICD des Aachen House of Integrative Production zählt insbesondere die effektive Vernetzung der wissenschaftlichen Prozesse des Exzellenzclusters zu den Aufgaben der Cross Sectional Processes (ICD F). Die Vernetzung erfolgt dabei durch die Implementierung feldgetesteter Maßnahmen, die vom ZLW/IMA der RWTH Aachen in Vorgängerprojekten vergleichbarer Größe und Komplexität entwickelt und an die Anforderungen des Exzellenzclusters adaptiert wurden. Das hieraus resultierende Maßnahmenset zum Management von Querschnittsaufgaben in interdisziplinären Kooperationsverbünden (vgl. Tab. 1) bietet die Möglichkeit, maßgeschneiderte Cross Sectional Maßnahmen (organisatorischer wie auch informationstechnischer Art) in unterschiedlichen Phasen der Netzwerkentwicklung anzuwenden und hierdurch die Quervernetzung zu unterstützen. Beispielhafte Maßnahmen stellen diesbezüglich die Durchführung und Organisation von Strategieworkshops auf der Führungsebene und Kolloquien auf Ebene der wissenschaftlichen Mitarbeiter dar, welche u. a. zur Erhöhung der Transparenz von Forschungsinhalten wie auch zur Steigerung der Kooperationsqualität beitragen. Darüber hinaus fallen Weiterbildungsangebote zur Förderung des wissenschaftlichen Nachwuchses in den Aufgabenbereich der Cross Sectional Processes, sowie Maßnahmen des Gender und Diversity-Managements. Ebenfalls nimmt die Implementierung eines clusterspezifischen Balanced-Scorecard-Ansatzes eine wichtige Rolle ein, der zum Controlling des gesamten Exzellenzclusters eingesetzt wird (vgl. Kap. 3).

Zur Koordination und Regulation der Quervernetzungsaufgaben bedarf es konkreter Praktiken des Managements im Sinne von (wiederkehrenden) Handlungen, mit denen Strukturen aktualisiert und reproduziert werden [Ort97, Sau05, Win02]. Diesbezüglich werden Praktiken und Maßnahmen im Rahmen der Cross Sec-

Tabelle 1 Maßnahmenset der Cross Sectional Processes

	Scientific Co-operation	*Education and Lifelong Learning*	*Equal Opportunities and Diversity Management*	*Knowledge and Technology Transfer*
Knowledge Organisation	Interner Wissenstransfer Performance Messung	Trainee Programme für das Cluster Doktorandencoaching	Gender Strategy Development	Wissensmanagement-systeme Expertenlandkarte
Research Organisation	Strategieentwicklung Communities of Practice	„Fit-Programm“ Studentische Forschungsvorhaben	Familie und Beruf (Quer und Wiedereinstieg)	Austauschprogramme für Wissenschaftler
Communication	Clusterkonferenzen Wissensplattformen	Wiss. Kolloquien Studentische Fachtagungen	Diversity-Teams Einbindung von Schülerinnen	Kunden-Forscher-Workshop
Knowledge Output	Integrierte Dissertations-betreuung Summer Schools	LLL-Seminarangebote	Internationale Industriearbeitskreise	Publikationsreihe Reviewmechanismen Literaturdatenbank

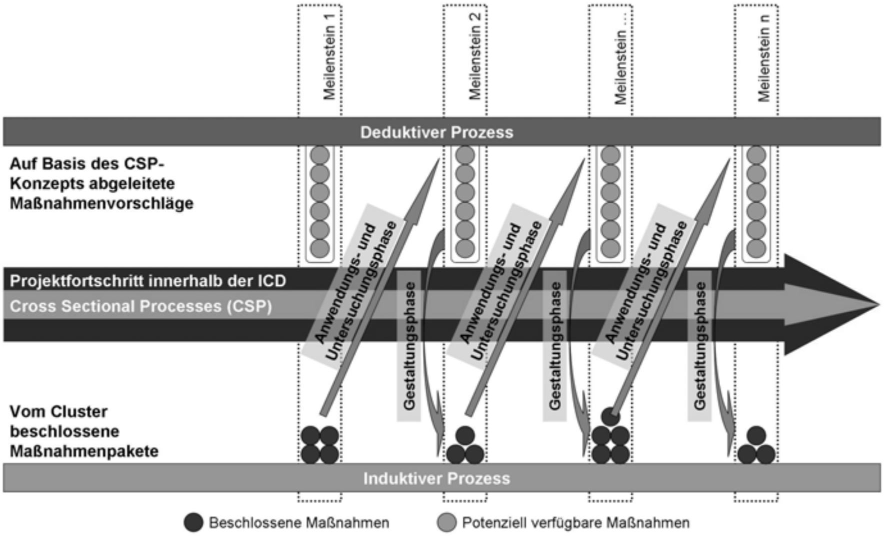

Abb. 3 Der Induktiv-Deduktiv-Ansatz von ICD F (ZLW/IMA der RWTH Aachen 2008)

tional Processes nach einem Induktiv-Deduktiv-Ansatz über die gesamte Projektlaufzeit weiterentwickelt (siehe Abb. 3). Dabei wechseln sich Anwendungs-, Untersuchungs- und Gestaltungsphasen iterativ ab. Auf diese Weise werden bereits eingesetzte Maßnahmen an aktuelle Bedarfe des Exzellenzclusters angepasst. Infolge der iterativen Vorgehensweise wurde u. a. die scorecardbasierte Performancemessung nach der ersten clusterweiten Implementierung in einem Workshop mit der Geschäftsführung des Exzellenzclusters reflektiert und überarbeitet.

3 Management und Controlling als wichtige Aufgabenbereiche im Exzellenzcluster

Damit die heterogenen Akteure gemeinsam die übergeordnete Zielsetzung erreichen können, die mit der Erzielung von Innovationen zur Steigerung der Wettbewerbsfähigkeit von Hochlohnländern beschrieben werden kann, ist ein Management der Quervernetzungsaufgaben notwendig, das die Kooperation der Akteure koordiniert und steuert. Die grundlegenden Herausforderungen, die bezüglich der Zusammenarbeit in einem heterogenen Netzwerk auftreten und die notwendigen Mittel, um Synergieeffekte im Exzellenzcluster nutzbar zu machen, werden im Folgenden beschrieben. Dadurch, dass der Exzellenzcluster einen Zusammenschluss von interdisziplinären, heterogenen Akteuren in einem forschungsbasierten Netzwerk darstellt, ergeben sich für viele Akteure deutliche Unterschiede zu ihrer gewohnten Organisationskultur bzw. ihrem parallel existierenden Geschäftsalltag außerhalb des Exzellenzclusters. Diesbezüglich beschreibt auch Ahrens (2004) [Ahr04], dass

> mit dem Netzwerkbegriff [. . .] deutlich gemacht [wird], dass die Handlungskoordination nach einem Modus erfolgt, der sich von den alternativen Formen Markt und Hierarchie deutlich unterscheidet. Das heißt, die Koordination und Steuerung von Netzwerken erfolgt nicht über Preise oder Anweisungen, sondern in erster Linie über vertrauensvolle Kooperation und Aushandlung [Ahr04].

So liegt die Annahme nahe, dass es für einen Lehrstuhl leichter ist, sich in die Struktur des Exzellenzclusters einzuordnen und mittel- bis langfristige Forschungsprojekte durchzuführen, wohingegen für einen Industriepartner eher kurzfristig erzielbare Produkt- und Prozessinnovationen von Interesse sind. Diese Annahme lässt sich ebenfalls durch den klassischen trade-off zwischen exploration und exploitation von Produkten bzw. Wissen beschreiben, durch den Netzwerke grundsätzlich charakterisiert werden [Ami04, Syd06]. Eine weitere grundlegende Herausforderung der unterschiedlichen organisatorischen Hintergründe der Akteure stellt z. B. die Herausbildung einer Netzwerk- bzw. Clusterkultur – in Form gemeinsamer Regeln, Konventionen und Routinen – dar, die sich erst mit der Zeit entwickeln kann [Sch03, Sau05]. Unumstritten ist jedoch die Tatsache, dass die Zusammensetzung heterogener Akteure zur Generierung von neuem Wissen förderlich ist, weil

> Netzwerke [. . .] das Potenzial zur Generierung, Prüfung und Integration von sehr unterschiedlichen Wissensbeständen in spezifischen und sich schnell ändernden Entscheidungssituationen [bergen] [Sau05].

Allerdings findet der Prozess des Wissensaustauschs und der Wissensproduktion in einem Netzwerk nicht ohne steuernde und koordinierende Maßnahmen statt, was Sauer (2005) [Sau05] wie folgt beschreibt:

> Der Ansatz, heterogene Partner in Forschungsnetzwerken zusammenzubringen, verspricht – aufgrund der Unterschiedlichkeit bzw. Komplementärkompetenzen der beteiligten Partnerorganisationen – einerseits hohes Innovationspotenzial sowie weitere Vorteile, wie z. B. die Verringerung von Konkurrenz, da unterschiedliche Märkte und Kunden angesprochen werden. Andererseits birgt dieser Ansatz Risiken, wie z. B. Kommunikations- und Anschlussprobleme aufgrund unterschiedlicher (Fach-) Sprachen und Arbeitskulturen [Sau05].

Demnach ist insbesondere das Management von Cross Sectional Processes in einem Exzellenzcluster wichtig, um Rahmenbedingungen zu schaffen, durch welche sich erfolgreiche Kooperationen der Akteure entwickeln können, die schließlich auch in Innovationen münden. So müssen Partner mit teilweise unterschiedlichen Interessen auf eine gemeinsame Linie gebracht, Kommunikationsprobleme zwischen denselben gelöst und Vertrauen als sozialer Kitt im Netzwerk aufgebaut werden [Oer04, Pet04, Sau05]. Dass jedoch Vertrauen nicht erzwingbar ist und zusätzlich Risikoaversion, insbesondere seitens industrieller Partner, ein Problem beim Wissensaustausch in einem Exzellenzcluster darstellen kann, muss seitens des Managements von Quervernetzungsaufgaben beachtet werden [Ker96]. Folglich bedarf es nicht nur passender Maßnahmen zur Quervernetzung der Akteure, sondern auch eines Instruments, dass die Leistung des gesamten Netzwerks misst und Ergebnisse an die Managementebene zurückführt. An welchen Stellen die wissenschaftliche Vernetzung des Exzellenzclusters weiteren Entwicklungsbedarf aufweist und inwiefern die Cluster-Performance mit einem Controlling-Instrument wie dem Balanced-Scorecard-Ansatz gesteigert werden kann, ist Schwerpunkt der folgenden Abschnitte [Wel10].

Die von Kaplan und Norton im Jahr 1992 entwickelte Balanced Scorecard stellt ein „Performance-Mess-System“ dar [Kap92], das ursprünglich als Kommunikations-, Informations- und Lernsystem innerhalb von Unternehmen konzipiert wurde. Der durch die ICD F aufgegriffene und modifizierte Balanced-Scorecard-Ansatz überträgt die aus dem Unternehmenscontrolling stammende Theorie auf das Controlling des Exzellenzclusters. Analog zum klassischen Ansatz nach Kaplan und Norton beinhaltet auch der clusterspezifische Balanced-Scorecard-Ansatz vier Perspektiven (Finanzielle Perspektive, Interne Perspektive/Forschungskooperationen, Lern- und Entwicklungsperspektive, Output/Kundenperspektive), doch wurden diese hinsichtlich der Eigenschaften eines heterogenen, wissensintensiven Netzwerks wie folgt modifiziert (vgl. Abb. 4).

Die vier Perspektiven bilden dabei einen Rahmen, durch den die übergeordnete Vision des Exzellenzclusters in strategische (Teil-)Ziele aufgeschlüsselt wird, welche allen Akteuren im Exzellenzcluster Orientierung in der täglichen Arbeit des Forschungsnetzwerks bietet. Inwieweit z. B. Teilziele erreicht werden, wissenschaftlicher Output generiert wird oder wie hoch die Zufriedenheit unter den Clusterakteuren hinsichtlich der Kooperationsqualität im Exzellenzcluster ist, wird in regelmäßigem Iterationen untersucht und an die Geschäftsführung zurückgeführt. Zu diesem Zweck wird als Hauptbestandteil der clusterspezifischen Balanced-Scorecard jährlich eine elektronische Befragung durchgeführt, die alle Mitarbeiter des Exzellenzclusters adressiert. Der standardisierte Online-Fragebogen deckt dabei die vier Perspektiven der clusterspezifischen Balanced-Scorecard ab. Die Struktur des Fragebogens ermöglicht sowohl die Generierung von vergleichbaren Kennzahlen, die mittels deskriptiver Statistik ausgewertet werden, als auch die Erfassung von qualitativen Aussagen der Befragten. Durch die ersten drei elektronischen Befragungen in den Jahren 2008 (Teilnehmerzahl: $n = 113$), 2009 ($n = 121$) und 2010 ($n = 116$), die sich an verschiedene Hierarchieebenen des Exzellenzclusters richtete (u. a. an die Professoren, die Geschäftsführung und die wissenschaftlichen Mitarbeiter), wurde

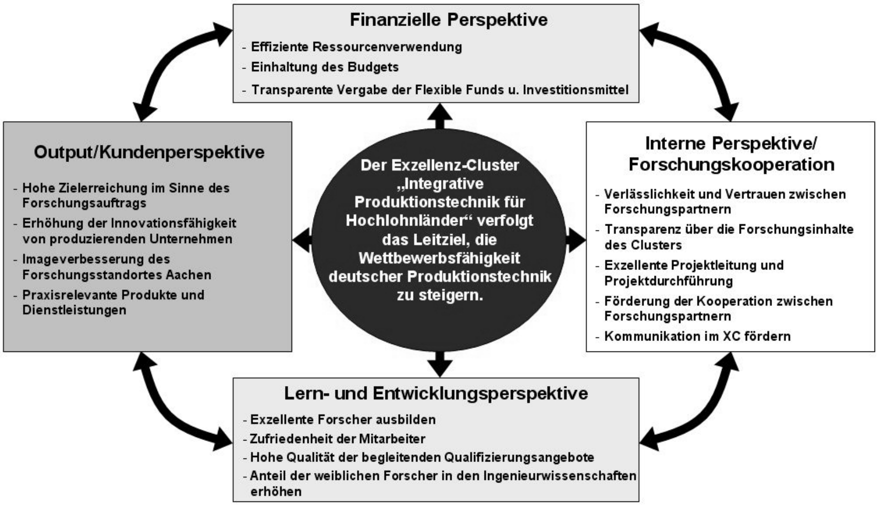

Abb. 4 Der Balanced-Scorecard-Ansatz im Exzellenzcluster Integrative Produktionstechnik für Hochlohnländer

eine Datenzeitreihe generiert, die den jeweiligen Status-quo der Netzwerkentwicklung in den einzelnen Jahren abbildet. Die Aufteilung der Fragebögen zwischen den verschiedenen Teilnehmerebenen ermöglicht dabei, Unterschiede und Gemeinsamkeiten hinsichtlich einzelner Aspekte zu untersuchen. Einige Fragen werden bewusst nur auf ausgewählten Hierarchieebenen gestellt wie z. B. die Beurteilung der effizienten Verwendung von finanziellen Mitteln im Exzellenzcluster auf Ebene der Professoren und Geschäftsführung. Die Antworten werden sowohl in aggregierter Form zur Beurteilung der Entwicklung des gesamten Exzellenzclusters genutzt, als auch in aufgeschlüsselter Form zur Reflektion einzelner Antworten auf den Hierarchieebenen herangezogen.

Die Daten der drei Balanced-Scorecard-basierten Befragungen verdeutlichen, dass sich die Antworten in aggregierter Form auf einer möglichen Skala (in Anlehnung an ein Schulnotensystem von 1 = positiv bis 5 = negativ) weitestgehend zwischen den Werten 2 und 3 bewegen. Ausgewählte Ergebnisse und Entwicklungen und daraus resultierende Handlungsempfehlungen, die von den Cross Sectional Processes mit der Geschäftsführung des Exzellenzclusters erarbeitet wurden, werden diesbezüglich in den nachfolgenden Abschnitten vorgestellt.

Als ein Resultat der Datenzeitreihe (2008 bis 2010) kann festgehalten werden, dass Nutzen und Qualität der wissenschaftlichen Kooperationen im Exzellenzcluster besser bewertet werden als zu Beginn der Projektlaufzeit. Ebenso wird der clusterweite Informationsfluss über Fortschritte in den einzelnen Teilprojekten als besser durch die Befragten eingeschätzt. Diese Bewertungen unterstreichen die Tatsache, dass das gegenseitige Kennenlernen der Clusterakteure untereinander sowie die damit verbundene gesteigerte Transparenz über Arbeitsinhalte und zunehmende Vertrauensbildung im Netzwerk eingesetzt hat. Unterstützende Maßnahmen der Organisationsentwicklung und des Wissensmanagements, die diese Prozesse beschleunigen, sind aus diesem Grund insbesondere während der Initiierung eines Exzellenzclusters wichtig. Organisatorisch ist diesbezüglich die vermehrte Durchführung thematischer Arbeitstreffen zu nennen (z. B. in Form einzelner Teilprojekttreffen wie auch in Form clusterweiter Versammlungen), die eine gezielte face-to-face-Kommunikation unter den Mitarbeitern fördert. Eine steigende Anzahl dieser formalen Treffen kann seit Beginn des Exzellenzclusters festgestellt werden, wobei diese zum Teil durch das Clustermanagement angestoßen wurden. In einem nächsten Schritt wird zusätzlich die Initiierung von informelleren themenspezifischen Arbeitsgruppen (Communities of Practice) angestrebt. Hierfür bedarf es auch geeigneter Tools zur Kooperationsunterstützung, die den Clusterakteuren beispielsweise den Austausch von Daten ermöglichen. Für diese Zwecke wurde ein clusterinterner BSCW-Server aufgesetzt, der künftig durch weitere, stärker interaktivere, Tools ergänzt wird. Vor diesem Hintergrund wird derzeit die zusätzliche Implementierung einer semantisch gestützten Wissenslandkarte für das Jahr 2010 geprüft.

Im Hinblick auf clusterspezifische Weiterbildungsangebote wurde aufgrund von Ergebnissen und Vorschlägen seitens der Teilnehmenden der ersten Befragungen ein entsprechendes Programm durch die Cross Sectional Processes und die Geschäftsführung aufgesetzt. So fanden im Jahr 2009 Seminare wie z. B. *Clusterspezifisches Projektmanagement für Führungskräfte oder Forschungsmethodik und wissenschaftliches Arbeiten in technikorientierten Handlungssystemen* statt, um die Ausbildung der wissenschaftlichen Mitarbeiter zu verbreitern und ihre Projektmanagementfertigkeiten zu schulen. Darüber hinaus wurde im Jahr 2009 mit der Einführung der Vortragsreihe „I did it my way – Karrierewege von der Hochschule in die Industrie“ den Clusterakteuren die Möglichkeit geboten, sich anhand von Vorträgen externer Referenten über verschiedene Karrieremöglichkeiten zu informieren und mit Vertretern – insbesondere aus der Industrie – persönlich ins Gespräch zu kommen. Auf diese Weise wurde zugleich die Außenwirksamkeit des Exzellenzclusters gestärkt. Dass bereits jetzt Vorteile für die Forschungs- und Entwicklungsarbeit im Exzellenzcluster durch den regelmäßigen Austausch zwischen Forschungs- und Industriepartnern existieren, wird von zunehmend mehr Clusterakteuren bestätigt. Darüber hinaus stimmt die Mehrheit der Befragten der Aussage zu, dass durch die Synergien im Exzellenzcluster mehr Forschungsoutput entsteht als in 80 gewöhnlichen Einzelprojekten. Es kann daher angenommen werden, dass die in Deutschland neuartige Organisationsstruktur eines Exzellenzclusters eine vorteilhafte Struktur für die Produktion neuen Wissens durch die Kombination verschiedener, interdisziplinärer Fachdisziplinen bildet [Sau05].

Erste Ergebnisse des gesamten Exzellenzclusters – insbesondere Forschungsoutput in Form von Publikationen und Präsentationen – werden des Weiteren von den Befragten mit Blick auf die dreijährige Datenzeitreihe vermehrt als sehr gut eingestuft. Um die Öffentlichkeitsarbeit weiter zu stärken, wurde u. a. neben der Einführung von öffentlichen Newslettern auch die Initiierung von Gruppen und Foren in Social Networks wie auch die Ausrichtung einer Konferenz zur Thematik des Exzellenzclusters geplant.

4 Zusammenfassung und Ausblick

Die Akteure des im Rahmen der bundesweiten Exzellenzinitiative gegründeten Exzellenzclusters Integrative Produktionstechnik für Hochlohnländer haben sich zum Ziel gesetzt, den Hochlohnländern insbesondere durch die Entwicklung innovativer Produktions- und Werkstofftechnik sowie neuer Formen der Arbeitsorganisation einen Wettbewerbsvorteil gegenüber den Niedriglohnländern zu verschaffen. Der integrative Ansatz stellt dabei durch die interdisziplinären Kooperationen eine große Herausforderung an das Management dar und bietet gleichzeitig die Chance zur Erzielung von Innovationen. Aus diesem Grund wird das Clustermanagement des heterogenen Forschungsnetzwerks durch die Maßnahmen der Cross Sectional Processes unterstützt, um die wissenschaftliche Quervernetzung auszubauen.

Durch die Auswertung der ersten drei Balanced-Scorecard-basierten Befragungen wurde dem Clustermanagement die Möglichkeit geboten, einzelne Teilaspekte des Exzellenzclusters auf verschiedenen Hierarchieebenen bewerten zu lassen und durch steuernde Eingriffe die strategische Ausrichtung des Netzwerks zu fokussieren. Auf diese Weise wurden Maßnahmen eingeleitet und Fortschritte für die Überführung des Exzellenzclusters von einer instabilen Initiierungsphase in stabilere, produktivere Netzwerkentwicklungsphasen erzielt. Wissenschaftlich stellt sich insbesondere die Frage nach der Übertragbarkeit des Ansatzes auf andere Forschungs- und Entwicklungsverbünde. In einem weiteren Teilprojekt von ICD F wird aus diesem Grund untersucht wie diesbezüglich ein Anwendungsmodell zum Management von Cross Sectional Process entwickelt werden kann, welches sich auf vergleichbare, hochkomplexe, wissenschaftliche Forschungskooperationen und Clustervorhaben insbesondere unterschiedlicher Fach- und Organisationskulturen übertragen lässt [Joo11].

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Organisation and Management of Integrative Research

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Abstract There has been a tendency to march off from the rising segregation of basic research, applied research and corporate research and development (R&D) towards a more dynamic and interactive process of generating interdisciplinary knowledge during recent decades. In this context a number of clusters of excellence were set up in 2006 under the German Excellence Initiative, including the RWTH Aachen cluster "Integrative Production Technology for High Wage Countries". The cluster brings together academics from a wide variety of disciplines, principally those of production engineering and materials science, in a common research network with the aim of researching integrative production theories. The organisational cluster structure thus represents with the Cross Sectional Processes an approach to the integrative networking of the cluster participants. The aim of Cross Sectional Processes is the academic interlinking of the integrative cluster domains and their research processes. For this reason, suitable individual measures for networking all cluster participants are being developed and implemented and unified solutions are being worked on for the management of an integrative cluster of excellence.

Key words: Organisation, Management, Integrative Research, Cross Sectional Processes, Cluster of Excellence

1 Introduction

Over the last few decades there has been a tendency to move away from the increasing segregation of basic research, applied research and corporate research and development (R&D) towards a more dynamic and interactive process of

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generating interdisciplinary knowledge. In order to respond to this tendency, the federal government and the federal states of Germany have initiated the Excellence Initiative. This aims to strengthen and maintain the status of Germany as a science and academic hub. A number of clusters of excellence were set up in 2006 under the Excellence Initiative, including the RWTH Aachen cluster "Integrative Production Technology for High Wage Countries". This brings together academics from a wide variety of disciplines, principally those of production engineering and materials science, in a common research network with the aim of researching integrative production theories. The highly complex and heterogeneous network in this cluster includes nineteen university institutes and Chairs, seven affiliated institutes, a number of non-university research establishments (such as the Fraunhofer-Gesellschaft) and various industrial and scientific consultants. Its organisational structure with the Cross Sectional Processes thus represents an approach to the integrative networking of the cluster participants to meet the challenge posed by its interdisciplinary nature and its organizational heterogeneity in the context of production engineering and materials sciences. This challenge lies in current academic trends such as a stronger integration of cognitive and information technology elements in production engineering and mechanical engineering. In addition, there are also external requirements placed on interdisciplinary research, such as those set by the funding strategies of the German Research Foundation (DFG), and the German Council of Science and Humanities (Wissenschaftsrat – WR) or the European Union. The aim of Cross Sectional Processes is the academic interlinking of the integrative cluster domains and their research processes. For this reason, suitable individual measures for networking all cluster participants are being developed and implemented and unified solutions are being worked on for the management of an integrative cluster of excellence. The Cross Sectional Processes pose the question:

How should networked, intensive academic and highly complex research co-operations within the cluster of excellence be organised in order to ensure highquality output?

This leads to the following objectives:

- Reports on the design elements for supporting the development of networks between highly complex research associations
- The development of an instrument for performance measurement in highly complex research co-operations
- The generation of a transferable application model for designing highly complex research co-operations.

2 State of the Art

In network theory, a distinction is made between four basic approaches, each of which takes as its theme a different aspect. Compared with social network analysis, neo-institutional network research and networks from a system theory perspective, structural analysis network approaches [Sau05] show the greatest convergence in respect of guaranteeing learning and knowledge processes in highly complex research co-operations. A structural analysis network perspective sees networks, like system theory, as "social systems that essentially expand and reproduce as a result and medium of interorganisational practices" [Syd06a]. The approach is subject to the acceptance of the duality and recursiveness of structure.[1] Consequently, the dealings of actors relate to existing structures, which are reproduced or transformed recursively by the behaviour of the actors (cf. ibid.). Network development therefore depends crucially on common social practices and network actors who, as "knowledgeable agents"[2] [Sau05] adapt them reflexively to the given environmental circumstances. The embedding of the network actors in both the network and the home organisation gives rise to a coevolutionary development via the transfer of specific networker knowledge from both organisations [Syd03]. Furthermore, SYDOW makes a distinction between strategic, regional, virtual and project networks [Syd06b]. Based on the following properties, the network type that the research network most closely resembles is that of a project network:

- time limits and selected partners with a highly fluctuating membership [Syd06b]
- a coordinating research unit and individual projects [Hun03]
- alignment of the innovation targets with specific topic areas [Syd06b]
- a new combination of implicit and explicit knowledge components holds a high innovation potential [Ahr03].

These qualities lead to the expectation that Cross Sectional Processes conceal both opportunities and challenges for participating organisations and research networks. According to SIEBERT, the best possible coordination in the network requires the following core conditions: firstly, the effectiveness condition of networks requires a higher degree of productivity than other types of coordination such as a market or hierarchy. For research networks, this means that the research output from the cooperation must be greater than that from conventional, non-integrative research. Secondly, the efficiency condition requires that all network actors have to be satisfied. In the case of research networks, this means that the utility from the cooperation must be greater than the costs of communication and cooperation borne by each actor [Sie06].

Since this represents a challenge for interdisciplinary networks, the structure and organisation of clusters of excellence and the corresponding Cross Sectional Processes should also consider the following aspects to guarantee a high quality cluster output:

- The heterogeneity of the cluster participants may lead to structural, cognitive and cultural challenges in respect of their cooperation and coordination, as different disciplines with different scientific methods and concepts come together

[1] The structures are according to Giddens, rules of signification and legitimation and resources of domination [Gid84].

[2] According to Windeler the actors monitor, supervise and control what happens "in that they recognise the potential and create test events, understand these and extend them. By doing this they control their behaviour or that of others by directing activities and securing them" [Win02].

(e.g. from production engineering, material sciences, information technology or economics).

- This creates both new academic potential and challenges in view of communication within the cluster and cooperation between individual disciplines [Sau05] [Röb04].
- One of these challenges, for example, is the process of understanding between interdisciplinary actors. These cultural challenges offer corresponding opportunities and risks for the performance of research networks.
- Project-orientated networks in particular are additionally characterised by a high degree of fluctuation of the actors. The continual coming and going of participants can have both a positive and a negative effect on the coherence of the entire network and may delay the process of network development [Syd06b]. This is a particular challenge for cross sectional tasks, as it is particularly high within a university research network because of time constraints on doctoral projects.

With reference to current challenges in the interdisciplinary management of academically orientated networks, the Cross Sectional Processes combine two approaches:

On the one hand, Cross Sectional Processes offer special services that aim to link the cluster participants in order to increase cooperation within the cluster and the academic output. Corresponding "Network Services" [Syd09, Buh09, Joo10] represent organisational measures such as colloquia for collaborators or digital knowledge management instruments. On the other hand the Cross Sectional Processes are in themselves a branch of academic research within the cluster of excellence that is continually examining how to optimise the interlinking of interdisciplinary academic actors. The results of a performance measurement system are used to this effect for instance for the continued strategic development of the whole cluster of excellence and of individual "network services".

3 Cross Sectional Processes and Procedures for Data Generation

In view of the current challenge of the interdisciplinary and integrative network management described above and against the backdrop of the next funding phase of the cluster of excellence, there is a need for further research with respect to achieving efficient linking of academic processes and therefore developing a model for the management of Cross Sectional Processes in the context of academic networks. In the example of the "Integrative Production Technology for High Wage Countries" cluster, the cross sectional processes are developing a model that shows specific measures to promote interdisciplinary cooperation and the development of the whole cluster. The aim is to transfer this to comparable networks and clusters.[3] A toolbox comprising cross sectional measures and addressing various lev-

[3] At this point it should be mentioned that every research project, including the example quoted here of the Cluster of Excellence "Integrative Production Technology for High Wage Countries" at

	Scientific Co-operation	Education and Lifelong Learning	Equal Opportunities and Diversity Management	Knowledge and Technology Transfer
Knowledge Organisation	Internal Knowledge Transfer Performance Measurement	Trainee Programs for the Cluster Postgraduate Coaching	Gender Strategy Development	Knowledge Management Systems Expert Map
Research Organisation	Strategy Development Communities of Practies	„Fit-Program" Student Research Projects	Family and Work (changing or re-entering a career)	Exchange Program for Scientists
Communication	Cluster-Conferences Knowledge-Platform	Scientific Colloquium Student Expert Conferences	Diversity-Teams Integrating Female Pupils	Customer-Researcher Workshop
Knowledge Output	Integrated Mentoring of Dissertation Summer Schools	LLL-Seminars	International Workshops with Industry	Publication series Mechanism of Review Literature database

Legend: Current measures executed by ICD F according to decisions of the steering committee of the CoE
Current measures executed bu the management board of the CoE
Further potential measures

Fig. 1 Toolbox of the Cross Sectional Measures

els of the internal cluster academic cooperation (knowledge organisation, research organisation, communication and knowledge output) is being implemented to this effect. The fieldtested measures that proceeded from the SENEKA project of the BMBF[4] ("service networks for further education and training processes") have been adapted to meet the requirement of an engineering research cluster. Based on wide project experience with respect to linking heterogeneous actors, the first measures in the toolbox were implemented with the agreement of the steering committee and the management board of the cluster of excellence (cf. Fig. 1).

For example, since the start of the programme two colloquia for employees have been held each year as part of the area "Internal knowledge transfer". One of their functions is to provide transparency regarding current research and work processes. With regard to "Performance measurement", an annual Balanced-Scorecard-based evaluation takes place over the full duration of the project. In addition, the area "Strategy development" deals with the organisation of strategy workshops. "Postgraduate coaching" takes place using a cluster-specific advanced education programme with seminars on project management and academic tasks in technology-

RWTH University in Aachen, is subject to certain project-specific constraints (e.g. spatial and temporal constraints) and that there is no standardised pattern for projects in interdisciplinary research networks. This means that an effective model must adapt to the individual contextual conditions of an academically intensive organisation.

[4] SENEKA was given a project duration of five years (1999–2004) within the framework of the pilot project initiative "Making Use of Internationally Available Knowledge for Educational and Further Educational Innovation Processes" of the German Federal Ministry of Education and Research (BMBF). The participants were 20 small and medium-sized enterprises, 3 large companies, 6 research institutes, and associated partners included more than 38 organisations and enterprises in Germany and the rest of the world (further information is available online at http://www.seneka.rwth-aachen.de/).

orientated action systems. Moreover, the "Gender strategy development" area is realized apart from other means by a series of lectures with the topic "I did it my way – career paths from university into industry". If one looks at the cross sectional measures in current use in Fig. 1, the focus is primarily set on the segment of scientific cooperation, stressing the overall challenge of cluster coordination.

A methodical approach that contains both quantitative and qualitative elements is needed in order to examine the success of these measures against the background of setting up a management model. For this reason three different methods were used, details of which are given below.

3.1 Indirect Evaluation

The first method represents the conversion of a cluster-specific Balanced-Scorecard-approach that relates to a model by KAPLAN and NORTON (1992) and describes a "performance measurement system" that was originally designed as a communication, information and learning system for companies [Kap92]. The approach was adapted to suit the needs of an academic cluster of excellence (for example, the evaluation of knowledge and cooperation processes is at the forefront of the approach) and has been implemented at RWTH Aachen both for the "Integrative Production Technology for High-Wage Countries" cluster and also, in comparable form, for the "Tailor-Made Fuels from Biomass" cluster [Wel10]. The approach is characterised by the measurement and comparison of performance indicators at various levels such as that of the sub-project leaders or management board and is based on a survey among all cluster participants to measure, among other things, the quality of academic cooperation or the academic output. The approach that is specific to the cluster of excellence follows that of Kaplan and Norton's original Balanced Scorecard and constitutes a "performance measurement system". It includes four adapted perspectives that relate directly to the overall vision of the cluster, namely the solution of polylemma of production technology. The perspectives are:

- the internal perspective/research cooperation
- the learning and development perspective
- the output or customer perspective
- and the financial perspective.

The breaking down of the overall vision into four perspectives and sub-objectives enables the measurement of academically orientated performance indicators such as the degree of interdisciplinary academic exchanges or the satisfaction of the employees. An internal cluster evaluation takes place annually in order to measure if the achievement of predefined sub-objectives and targets. This annual iteration enables information to be gathered and analysed and, working with the managers of the cluster, recommendations for action to be worked out. This is how the performance of the cluster as a whole is reflected and a controlling of the academic network is made possible.

To date three evaluations with an average of 117 participants have been implemented. Unlike KAPLAN and NORTON, who do not describe a specific method for the generation and collection of performance indicators, a semi-standardised questionnaire is used. This was developed by the persons in charge of the Cross Sectional Processes and the management board of the cluster. In this manner, performance indicators such as the cooperation quality of the academic network were made measurable. Descriptive statistics were used to analyse and compare the indicators. Figures including the generated arithmetic means and standard deviations of the individual questions are used as a basis of annual comparison in order to derive recommended actions for steering the cluster of excellence.

3.2 Direct Evaluation

Added to the annual Balanced-Scorecard-based evaluation, which represents an indirect form of evaluation, cluster-specific meetings and other events (e.g. colloquia for employees) are evaluated directly with semi-standardised questionnaires by the participants at the end of the event concerned. This method is used to obtain additional feedback on the use of individual cross sectional measures at any particular stage of the network development of the cluster of excellence.

3.3 Guided Expert Interviews

Compared with the two previous approaches of performance measurement and other forms of direct evaluation, guided expert interviews are a purely qualitative method of generating data. For the cluster of excellence, 25 interviews were conducted at various levels of the hierarchy, covering members of all sub-projects in the cluster. Due to the fact that professors, leading researchers, members of the management, sub-project supervisors and research assistants were interviewed it was possible to obtain comprehensive information about already implemented and potential future cross sectional measures.

3.4 Overall Analysis of All Data and Triangulation

With the grounded theory approach, a theoretically based style of research from the Chicago school of symbolic interactionism, it is possible to use, for example, interviews, field observations, documents and statistics to develop a theory ("grounded theory") based on the data [Gla08, Str96, Str08]. This "grounded theory" method in qualitative social research is widely used for developing organisational management theories and models that reflect a complex social reality. For this reason, it is particularly important to collate the data that has been previously generated by using the three methods described above. During this triangulation process, hypotheses are formulated that describe reports on advancing and restricting factors of network development and aim to secure the high quality of the academic output at any given stage of the network's development (initiation, stabilisation, permanence) [Ahr04]. To obtain further insights into the internal structures of clusters of excellence, an external analysis is also looking at the cross sectional data and processes of other clusters of excellence in Germany.

3.5 Preliminary Results

The preliminary results of the annual performance measurement, the direct evaluations and the guided expert interviews highlight various aspects that must be taken into account in order to support the high quality of the academic output of the Cluster of Excellence.

Based on the triangulation, the data make obvious that more intensive cross sectional activities at the level of integrative cluster domains[5] are important for a successful cluster development. These should preferably be implemented in the initiation phase of the cluster and can, for instance, take place during regular meetings of the staff in order to promote exchange of the sub-project leaders and research assistants in a domain.

As a reaction to the results of the Balanced-Scorecard-based evaluations carried out in 2008 to 2010, it was necessary to optimise the linking of various integrative cluster domains. A corresponding form of a network with a stronger content has been implemented by the management of the cluster with so-called 'demonstrators'. These can be regarded as highly networked sub-projects of the cluster that integrate research assistants from different integrative cluster domains and/or individual industrial partners. In doing so a greater level of scientific networking can be achieved on the one hand and a more intensive inclusion of applied research is realized on the other hand.

The results of the Balanced Scorecard highlight the fact that the personal benefit to academics of attending cluster-specific meetings diminishes as the number of persons attending the meeting increases. If this aspect is borne in mind, then regular meetings of smaller groups (e.g. sub-projects and integrative cluster domains) are beneficial to internal cluster cooperation, compared with frequent meetings in the style of a plenary session.

In view of the reports from the guided interviews, the role of the (sub-) project leaders requires a redefinition according to their role as "knowledgeable agents" [Sau05]. This is the principal group of people who integrate and transfers project-specific knowledge, both into the relevant integrative cluster domains and

[5] In the cluster of excellence "Integrative Production Technology for High-Wage Countries", interdisciplinary research is processed in six integrative cluster domains (ICDs).

into the overall cluster of excellence. Cluster-specific further education offers prepared by (sub-) project leaders about their tasks in the cluster must therefore be explicitly implemented and communicated in the initiation phase and supported by the individual institutes. Consequently the project leaders must also be offered the capacity to reduce the trade-off between work in the cluster of excellence and work within the context of their other obligations to the institute.

Moreover, the data analysis underlines that in spite of a highly rated use of digital tools for the networking of actors, the tools currently implemented (such as the common data platform) are not regularly used. For this reason, possible approaches to a solution include greater integration of the internal cluster data platform into the official cluster home page, and the integration of a semantic network and methods of knowledge retrieval into the internal data platform in order to associate content intelligently with individual academics and projects. A more interactive form of digital networking is also desirable by the cluster participants according to the analysis of data, as this can have a beneficial effect on increasing the intensity and quality of cooperation.

The regular use of the Balanced-Scorecard-approach has proved to be an important cross sectional measure, as it allows the research activities of the cluster of excellence to be shown by a comparable set of (particularly) quantitative indicators and data at all stages of the network's development. The performance measurement system supports the reflection and redesign of already implemented activities and in addition enables the correction of medium- to long-term management strategies. As to the process in which long-term strategies are critically examined by internal management, KAPLAN and NORTON refer to "double-loop learning" [Kap97].

In view of the production engineering-orientated focus of the cluster, the Balanced Scorecard approach serves to measure the status quo of the cluster performance regularly in order to support, among other things, the high quality of the academic output or the training of excellent academics. Efforts must be made to further adapt the tool to meet the current requirements of a production engineering-orientated cluster by holding regular workshops with management, as this makes the results easier for all groups of actors to use. A stronger bottom-up approach during the definition of cluster-specific indicators for future projects is also advisable in order to improve the intrinsic motivation of all the actors in the cluster of excellence to play a greater part in the ongoing Balanced Scorecard-based evaluation.

With regard to the cross sectional measures to be used in a cluster of excellence it should be noted that the high staff turnover of the university environment leads to a delay in the development of the characteristic network phases (initiation, stabilisation and continuity). Network management instruments such as plenary sessions, strategy workshops, colloquia for employees and also data and knowledge management systems therefore compensate for the effects of personnel fluctuations at all stages of network development, as these also serve to transfer knowledge within the cluster.

4 Industrial Relevance

Within the framework of the Cross Sectional Processes a management model for the networking of scientific orientated clusters of excellence was developed with the aim of transferring these management practices to comparable networks and clusters. In the light of the sustained excellence initiatives throughout Germany, this is particularly promising, as there is a great need for research on a scientific concept of processing network tasks. Given the global trend towards enhanced interdisciplinary work in projects, the model for managing Cross Sectional Processes, like the tools that have been examined for networking purposes in the context of the cluster of excellence, can be evaluated as industrially relevant. Partners from industry are being included in project networks to an augmenting extent and co-operations within them need to be successfully initiated and made continuous.

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Part II
Next-Generation Teaching and Learning Concepts for Universities and the Economy

An Electronic Engineering Mobile Remote Laboratory

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Abstract A new architecture for the development of a wireless remotely controlled laboratory with focus on educational applications in electronics engineering is presented. The Internet is used as the communication infrastructure to enable remote students to access experimental equipment via mobile devices. The remote lab aims to support access of clients running on PCs or Personal Digital Assistant (PDA) devices while the server implementation was based on LabVIEW programming language. Experimental tools were created to allow users to collect data and information about the experiments, giving encouraging initial results where students are able to undertake simple engineering remote experimentation. Further experiments are envisaged and international collaboration is underway.

Key words: Remote Labs, Mobile Content, Electronics Engineering Education, Curriculum Development

1 Introduction

The internet was first used in 1994 as a tele-control medium and subsequently applied in an educational context in 1996 when web-based laboratories were introduced by universities worldwide in undergraduate engineering courses [ABCS96,

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EPFH99, SXD+99]. The evidence that the field of remote engineering has matured are overwhelming, particularly as indicated by the number of remote laboratories in operation today. Furthermore, the range of disciplines being taught continue to grow and collaborations between universities all over the world are becoming increasingly common [LG05]. Related training courses have also been explored in chemistry, physics, and electrical engineering and other interesting setups include remote experiment and virtual labs for wind tunnels, a virtual laboratory for exploiting DSP algorithms and a learning tool for chip manufacturing [JAP+08]. Recently, a distributed laboratory was developed for the execution of virtual scientific experiments superimposed on a Grid infrastructure as part of a master degree in information networking [CETK07]. The opportunity to provide students with remote access to experimental hardware and the ability to offer flexibility in time and place in which laboratories are conducted are also becoming powerful motivations for the field [ATH05]. Additionally, the recent advances in mobile technologies have lead to an increase in the number of internet users accessing information via mobile devices and the number of applications designed for such devices is growing and becoming increasingly popular. From the pedagogical viewpoint, students' expectations on how and when they learn are also creating increasingly heavier demands upon all aspects of their learning as young people are making mobile devices an extension of their personal space and fundamental to their daily lives. In response, the world is moving very rapidly to engage with the opportunities and flexibility offered by mobile technologies [KV07].

Mobile remote solutions may therefore be attractive tools in enhancing access to practical experiments as they offer many different possibilities for applications in industry and education because they are not subjected to limitations of location and time [DM06, TPA06]. This, in combination with today's easy access to broadband internet, is transforming the way e-learning is carried out, allowing a higher level of interactivity and providing virtual environments closer to real ones. Hence, mobile remote systems can be very useful when applied to solutions involving high costs of people and equipment transportation. Different universities and institutions could share laboratory resources, expensive equipments and experiments by means of a cooperative network of remote systems.

In this paper, the possibility for students to access remote experiments via mobile devices is presented. The proposed approach is to implement a client Personal Digital Assistants (PDA) which may be programmed in LabVIEW, with a module that suits applications on handheld devices. Communication between the server and the mobile client was based on direct TCP/IP programming to facilitate data transfer through the internet. Experimental tools were created to allow the user to collect data and information about the experiments. Initial results are very encouraging, with students able to undertake simple engineering remote experimentation and further experiments and international collaborations are underway.

2 The LabVIEW PDA Module

An effective way of improving technology-enhanced engineering education is to combine theory and practice simultaneously in the same lesson. The most convenient and popular environment to implement virtual and remote experimentations is probably the Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW) programming language, which has been extensively used for such purpose. LabVIEW is high-level user-friendly graphical programming language developed by National Instrument (NI) for use by scientists and engineers, particularly for data processing and acquisitions applications. LabVIEW employs special controls to form instructions and icons to build subroutines, wired together in order to define the flow of data through the program. In this context, LabVIEW is a visual language and not text-based where the code is governed by a series of rules based syntax such as commas, periods, semicolons, square brackets, curly brackets, round brackets, and others. To the contrary, LabVIEW flowcharts the code as it is written to produce a program in a timely and efficient manner. This programming approach is based on building blocks called Virtual Instruments (VIs); each contains three main parts: front panel; block diagram; and icon/connector. The front panel is a means of interaction between the user and the block diagram (program) when the program is running. Users may utilize the front panel to control the program, alter inputs, and monitor changes, updates and other variations in real time. Indicators are program outputs used to show the status of program variables, parameters, flags or other types of data, states, and other information. Front panel objects appear as terminals on the block diagram where every control and indicator has a corresponding terminal which contains the graphical source code. Additionally, certain functions and structures which reside in built-in LabVIEW VI libraries are used in the block diagram.

A special add-on LabVIEW module has also been devised by National Instruments to allow one to run LabVIEW virtual instruments (VIs) on PDA execution targets. The module is a good tool for creating data acquisition and remote system monitoring applications that are both portable and flexible. The LabVIEW PDA module is usually operated with an emulator that can be used to test the application inside a simulated environment to mimic the behavior of the actual PDA. It gives additional flexibility in the design and testing and establishes greater confidence that the applications will behave as intended. It facilitates the development of graphical environments to create custom applications for a multitude of mobile devices and PDAs. The programmer is thus given the choice to select the appropriate operating system that will be implemented in the design before commencing with writing the program. In addition, the LabVIEW PDA module allows the creation of custom, user-defined applications for Palm, Windows Mobile for Pocket PC and Windows CE devices. This can be achieved with a LabVIEW programming environment on the same way it is made for a PC application but deployed into a PDA. It also allows the development of data acquisition applications with Compact Flash and PCMCIA DAQ cards. Furthermore, the PDA module includes some libraries of sub VIs developed to take advantages of additional resources available on PDAs and Smartphone, like short message services (SMS) and telephony. Besides, it is also possible to use most of the known functions and APIs available when developing applications for PCs with the LabVIEW PDA module for the most common operating systems found on these devices, like Windows Mobile, Palm OS and to deploy it for emulated devices or real ones via the proper synchronization tool like Microsoft Activesync for Windows Mobile. Due to the limited graphical capabilities of these devices, however, the controls and indicators are sized and scaled and the functions palettes are reconfigured.

3 Architecture of the Mobile Remote Lab

The application of interest here is to enable electrical engineering students to revise material anywhere at anytime. The material may be in the form of text, equations, figures, intimations, and circuits. However, it is also important for students to conduct experimental work virtually by simulation or remotely by accessing laboratory set-ups through the internet. This may be achieved utilizing the graphical interface capability and web publishing facility of LabVIEW. In addition, a lesson may consist of text, figures and circuits and necessitates the use of multi-screens design. This requires the program to navigate from on page to another due to the limited capacity of the screen. Several methods have been implemented to manage this situation, including the use hyperlinks and buttons, as well as the attempt to interface LabVIEW with other programming languages such as Java. The use of tab pages has however been found the most suitable convenient solution to navigate between pages in this particular application.

A system was designed into the architecture shown in Fig. 1 to perform remote real electronic experiments via the internet. This architecture shows the methodology of how remote clients will connect to the remote lab. The user interface and the control of the lab hardware were developed with LabVIEW virtual instruments (VIs) to design front panels which resemble the front view of a real oscilloscope and a function generator, for example, and to have nearly the same functionalities as real devices. These VIs were then embedded into HTML and published in the Web server which also hosts the remote laboratory home page with information about the implemented exercises, as well as the links to system login. The front panels could then be remotely reached via a standard Web browser which does not require of the user any prior knowledge of LabVIEW to take advantage of the system facilities. In fact, the client simply needs a standard Web browser and a proper version of LabVIEW run-time engine that contains some libraries and web browses' plug-ins. This software is available free of costs at the National Instruments website and is automatically downloaded on the first attempt to access the system. In addition, the driver software has an application programming interface (API), which is a library of VIs, functions, classes, attributes, and properties for creating applications. This

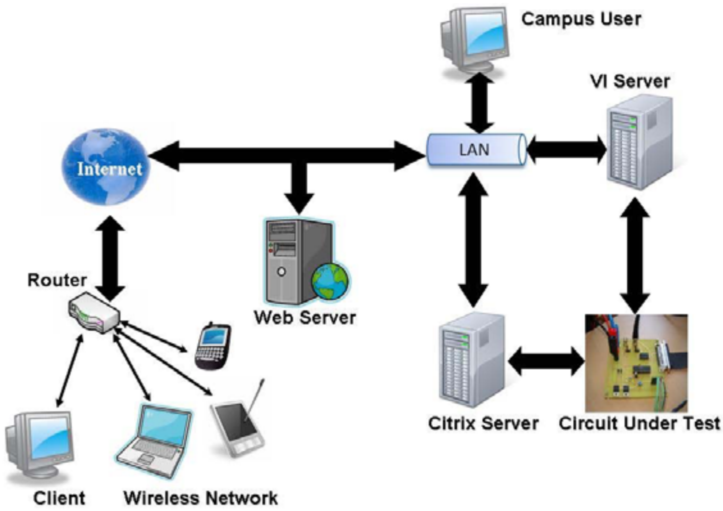
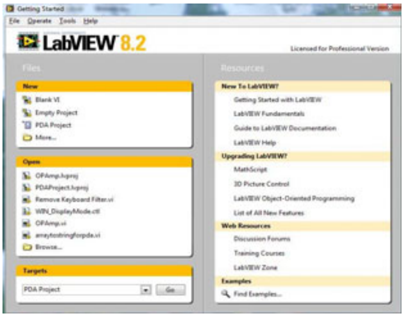


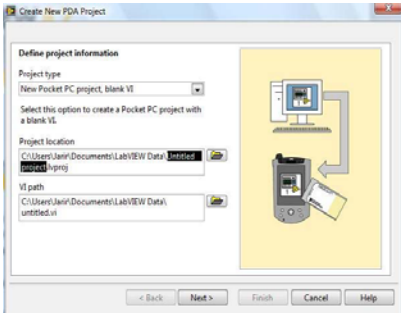
Fig. 1 Mobile Remote Laboratory Architecture

library of polymorphic VIs replaces large parts of a complex DAQ application with a simple configuration dialog.

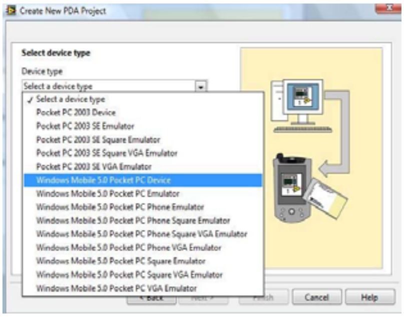
Students may be able to enter a remote laboratory and carry out electronics experiments from anywhere at anytime. The proposed approach is to implement a client PDA which may communicate with the Web and VI severs directly with transmission control protocol (TCP), internet protocol (IP), or user datagram protocol (UDP), being the basic standard protocols for network communications and data transfer through the internet. TCP/IP communication provides a simple user interface that conceals the complexities of ensuring reliable network communications. TCP describes communication between applications and permits multiple simultaneous connections which must be established prior to data transmission and thus necessitating the specification of an address and a port at that address when a client requires communicating with a server. A connection is initiated by waiting for an incoming connection or by actively seeking a connection with that specified address. After a "handshake" between the two applications, TCP sets up "full-duplex" communication between the client and a server. On the other hand, IP is a "connectionless" communication protocol responsible for routing a packet to its destination. LabVIEW offers an API for developing applications that includes TCP/IP and UDP functions used to create client and server VIs on all platforms. The responses are read, for example, with the aid of the NI DAQmx driver software. Only one user can however access the remote lab at a time, therefore each user is allocated a thirty minutes time-slot to access the system by first inserting a username and a password. If both are valid, the system enables access to the lab.



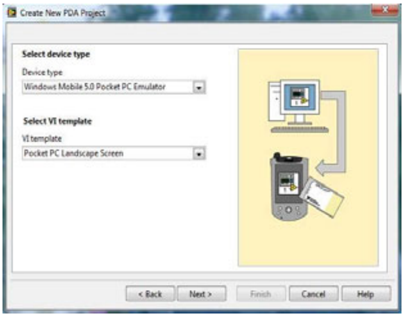
a) "Getting Started" with Mobile Module



b) "Create New PDA Project" Option



c) Device Type Selection



d) Landscape or Portrait Screen Options

Fig. 2 Building a Project on LabVIEW PDA Module

3.1 Programme Design

A new PDA application is built on the LabVIEW when the programmer selects a PDA project from the targets list on the "getting started" screen as shown in Fig. 2a. The next screen is a "create new PDA project" that allows the selection of a project type from project type list. A new VI can be created by selecting "blank VI", whereas import VI is used to open an existing VI template, determine the project location and VI path. The project files are then to create on the selected path as shown in Fig. 2b. The device type is subsequently chosen from a list which conforms with actual the PDA operating system Fig. 2c. Another list also appears to select VI template as a pocket PC landscape screen or pocket PC portrait screen Fig. 2d.

The application of interest here is to enable electrical engineering students to access the content of the "Analog Electronic" course at Princess Sumaya University for Technology. The main part of the course focuses on the design, analysis and applications operational amplifiers in electrical systems. The material usually takes the form of text, equations, figures, animations, circuits' diagrams, displays and graphs. This requires the program to navigate from on page to another due to the

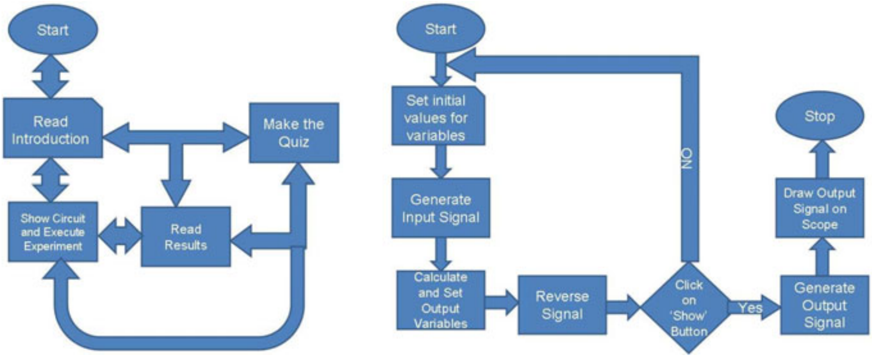


Fig. 3 Program Flowchart

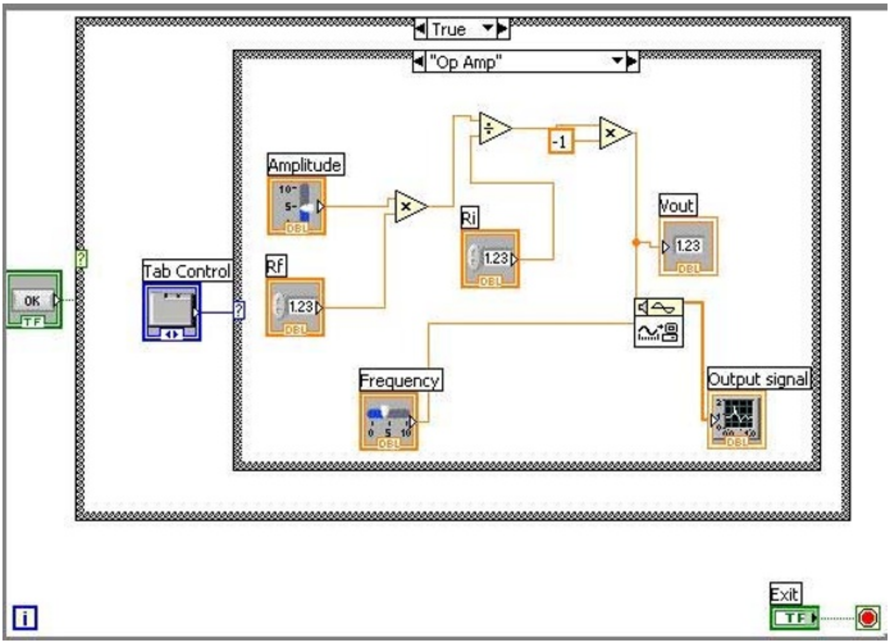


Fig. 4 Block Diagram of the LabView Application Program

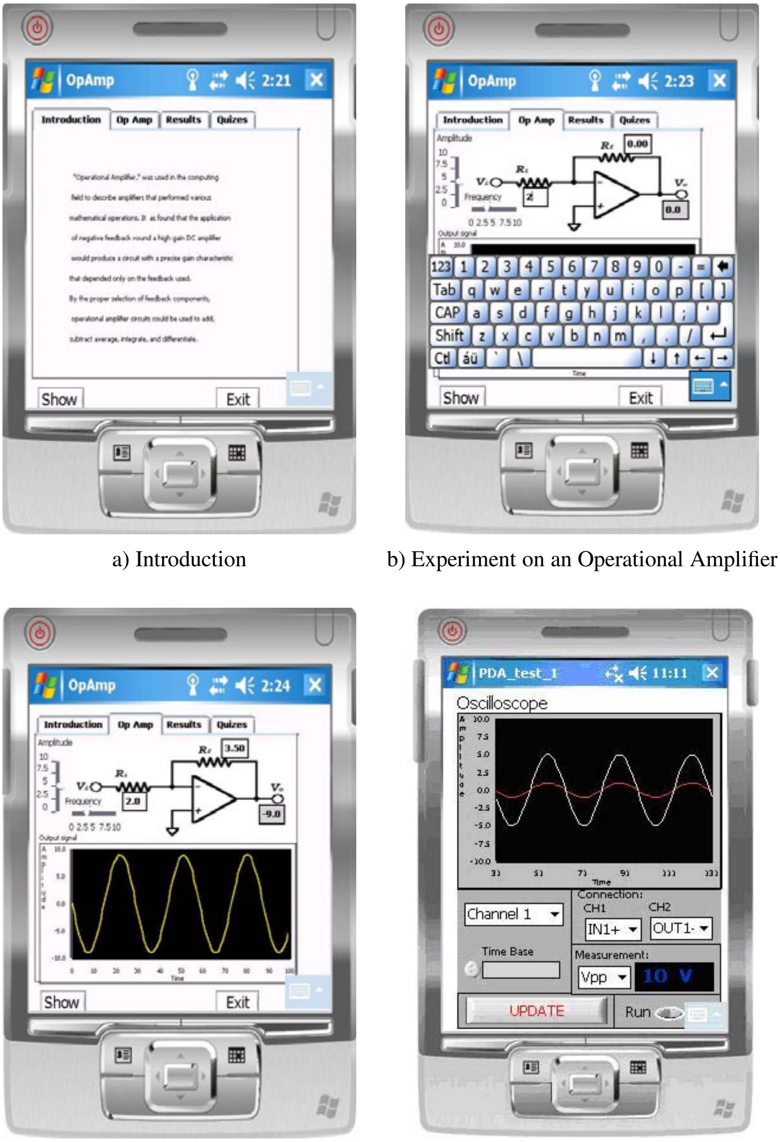
limited capacity of the screen. Several methods have been implemented to manage this situation, including the use hyperlinks and buttons, as well as the attempt to interface LabVIEW with other programming languages such as Java. The use of tab pages has however been found the most suitable convenient solution to navigate between pages in this particular application.

The first tab page contains an introduction about the subject of the lesson. The student can revise the lesson before conducting experiment. The next tab is op amp circuit figure with variable controller and scope. The user can see the circuit and set the variables; the frequency and amplitude for the input signal, the value of resistances. The program then generates the signal from there set values of frequency and amplitude, and feeds this signal to input of the op amp to produced the output, when the ‘Show’ button clicked then the op amp generate the output signal and draw it on the scope as shown in Fig. 2. In the result tab page the user can read a conclusion for the experiment and make an offline quiz in the last tab page. This tab page is designed to ensure students’ understanding and comprehension of the lesson and experiment. The student can navigate tab pages forward and backward and content of the lesson at any time.

4 Results and Discussion

The types of experiments under consideration were mainly electronic circuits at the junior undergraduate level for electrical engineering students at the Princess Sumaya University for Technology. Clients were designed for PDAs as well as for Windows PCs and requests from both were treated seamlessly by the server. Due to resources constraints of PDA devices, not all the features designed for a client running on a PC are performed when accessing the system via PDAs, but this can be managed just by changing the client application. A simple experiment to generate a number of waveforms with varying amplitudes, frequencies and shapes was initially performed remotely on a PDA to control and simulate an actual function generator. The most important consideration, however, was the limited resources of mobile devices compared to PCs which lead to a reduction of the features available for designing mobile remote laboratory. Nonetheless, the proposed solutions remain applicable to a number of experiments such as an operational amplifier which can be used to implement a number of mathematical operations such as summing two signals or subtracting them; integrating or differentiating a signal, detecting its peak, or even generation one, in addition to many other applications. One experiment was performed on an operational amplifier employing the proposed mobile remote lab as shown in Fig. 5, where a student first goes through an introduction explaining the main feature of the device and its operation, then an output for an inverting amplifier is displayed and the gain calculated. The student may also vary the frequency of the signal or its amplitude and observe the effect on the signal output and gain in real time.

In Fig. 5, it can be seen that the student can adjust the appropriate knobs until the required conditions have been satisfactorily achieved thereby giving the possibility to access the equipment directly and providing the student with an environment that mimics the actual one. In cases where real measurements are required rather than just controlling equipment, the measured data can be made available through the LabVIEW program e.g. in the format of an excel-sheet, for further analysis, enabling the students to directly compare the prognoses from the model with the results of their own measurements. In this context further experiments are being carried out to see how students perceive this remote lab technology, particularly with a laboratory such as the electronics lab, where sharing of expensive equipment is of paramount importance. This remote laboratory is to be integrated in the final



a) Introduction

b) Experiment on an Operational Amplifier

c) Amplifier Output and Display

d) Amplifier Gain Calculation

Fig. 5 Results of the Mobile Remote Lab

examination of the lecture giving an opportunity to verify whether the theoretical knowledge from the lecture has been transferred to practical knowledge that can be applied to a real world scenario by the students. where initial results have been encouraging as students able to undertake simple engineering remote tasks. Further experiments are being prepared.

5 Conclusions

A new wireless remote lab system was developed to enable students to access experiments via the internet from their mobile devices. The types of experiments under consideration were mainly electronic circuits. Student clients were able to access the remote lab using a PDA which communicates with the server controlling the equipment. The most important consideration, however, was the limited resources of mobile devices compared to PCs which lead to a reduction of the features available for designing mobile remote laboratory. The proposed solutions however remain applicable to other labs and experiments because they are easy to adopt standard solution. The initial results are very encouraging, with students able to undertake simple engineering remote experimentation. It can be still argued that learning environments will remain a combination of wired and wireless for the foreseeable future as not all affordances offered by wired environments are transferable to small mobile devices. Further experiments and international collaborations are underway.

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Ein Planspiel zur Vorlesung Projektmanagement für Physiker

Alexander an Haack, Philipp Wolters, Eckart Hauck, Sabina Jeschke

Zusammenfassung Die jüngere Lehrforschung sowie Initiativen wie CDIO.org sehen eine Verbesserung der universitären Lehre weiterhin in einer stärkeren Verknüpfung der zu vermittelnden Theorie mit praktischen Erfahrungen. Am Institut für Unternehmenskybernetik e.V. (IfU) wurde vor diesem Hintergrund das Planspiel PM-Key für die Vorlesung „Projektmanagement für Physiker" entwickelt und mit Hilfe des neu geschaffenen Online-Portals ASiGo als Browserspiel eingesetzt. In diesem Beitrag wird die Grundlage dieses Planspiels – das IfU Key-Planspielkonzept – erläutert sowie ein Vorgehensmodell präsentiert, welches das standardisierte und schlanke Erstellen neuer Inhalte nach diesem Konzept ermöglicht. Des Weiteren wird dargestellt, wie Plattform und Browserspiel technisch umgesetzt wurden und welche Ergebnisse und Erkenntnisse der erste Live-Test im Sommersemester 2011 erbracht hat.

Schlüsselwörter: Planspiele, Vorgehensmodell, Lehre, Projektmanagement

1 Projektmanagement für Physiker im Jahre 2011

Auch wenn das weit verbreitete, auf universitäre Forschung zentrierte Berufsbild von Physikerinnen und Physikern dies nicht direkt nahelegt, spielen seit langem schon für diese Berufsgruppen auch fachfremde Kompetenzen wie z. B. Projektmanagement eine wichtige Rolle [KS10]. Und auch in der klassischen Domäne der Forschung und Entwicklung prägen heute viele Verbund- und Großprojekte die Landschaft naturwissenschaftlicher Arbeit. An den Grenzen heutigen Wissens sind Fortschritte häufig nur noch durch multidisziplinäre Kooperation zahlreicher Experten und der Ressourcen mehrerer Kapitalgeber möglich. Das planvolle Zusam-

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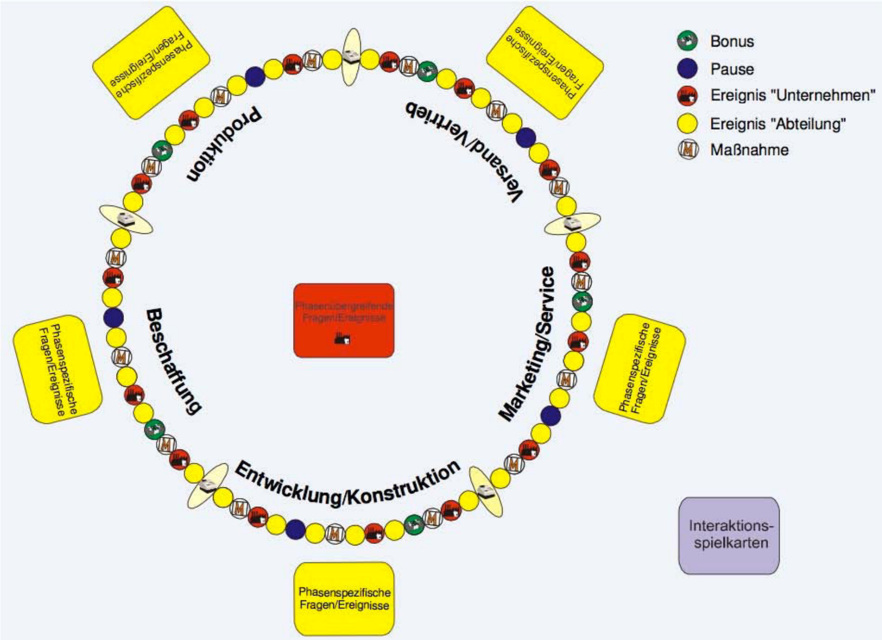

Abb. 1 Spielbrett des IfU Key-Konzept Planspiels „Q-Key"

menwirken mehrerer Akteure unter anspruchsvollen Zeit- und Kostenrestriktionen gewinnt im Sinne wachsender Leistungsfähigkeitsansprüche immer mehr an Bedeutung. Aus diesen Gründen bietet das Institut für Unternehmenskybernetik e.V. (IfU) an der RWTH Aachen im Bachelorstudiengang Physik die Veranstaltung „Projektmanagement für Studierende der Physik (PMP)" an, die von den Grundsätzen der Kybernetik geprägt ist. Die Befähigung für gutes Projektmanagement wird gebildet aus organisatorischen und psycho-sozialen Kompetenzen des Individuums und der Gruppe, die sich in Form von Methoden- und Problemkenntnis sowie -verständnis äußern. Projektmanagementkompetenz lässt sich nur begrenzt in der theoretischen Lehrsituationen einer Vorlesung vermitteln, sondern muss in praktischer Erfahrung erworben werden. Für derartige Lernsituationen eignet sich das didaktische Mittel des Planspiels [Ves04]. Im Falle von PMP zielt das eingesetzte Planspiel „PM-Key" auf die folgenden Lehr-/Lernziele ab [Roh92]:

- Vermittlung von Projektmanagementfachwissen und -problemverständnis (kognitive Lehr-/Lernziele)
- Vermittlung von Projektmanagementmethoden (instrumentelle Lehr-/Lernziele)
- Entwickeln eines Projektmanagement-dienlichen Verhaltens (affektive/emotionale Lehr-/Lernziele)
- Vermittlung von Motivation am Erlernen von Projektmanagementwissen (pädagogische Lehr-/Lernziele)

Hierbei kann das IfU auf eine mehr als zehnjährige Erfahrung in der Erforschung, Entwicklung und Anwendung von Planspielen zurückgreifen [HS03, HMJ10]. Ende 2010 startete am IfU das Projekt „RWTH Academic Simulation Game Portal" (ASiGo). ASiGo baut auf dem brettbasierten Planspiel Q-Key auf (Abb. 1). Q-Key wurde entwickelt, um die Mitarbeiter von Industrieunternehmen für Qualitätsmanagement nach dem Total Quality Management Ansatz (TQM) zu sensibilisieren [Haf99]. Eine spätere Variante dieses Planspiels war das 2004 entwickelte Micro-Key, das auf gleiche Weise die Kooperationsfähigkeit von Kleinstunternehmern schult [Nus04]. Beide wurden später auf eine HTML-basierte Softwareversion portiert [HMJ10]. Aus diesen Arbeiten entwickelte sich das IfU Key-Konzept für Planspiele.

2 Das IfU Key-Konzept & ASiGo

Dieses Konzept für Planspiele ist darauf ausgerichtet, das Bewusstsein für die zentralen Herausforderungen einer realen Problemstellung zu erhöhen und hierüber Lösungswege sowie in zweiter Instanz zugehöriges Fakten- und Verständniswissen zu vermitteln. Ein Key-basiertes Planspiel lässt sich wie folgt zusammenfassen: Fünf Personen bilden eine Spielgruppe, in der jeder eine unterschiedliche Rolle in einer anwendungsbezogenen Problemstellung übernimmt. Dies können beispielsweise verschiedene Abteilungen eines Unternehmens sein, das seinen Gesamtgewinn maximieren möchte und dabei auf das geschickte Handeln der teilhabenden Akteure angewiesen ist. Jeder Spieler wird mit spezifischen und übergreifenden Ereignissen konfrontiert, auf die er reagieren muss. Entsprechend des Ergebnisses eines Würfelwurfes ergründet der Spieler mit mehreren Spielsteinen das Spielfeld und lernt so die Handlungsalternativen des Planspiels kennen, die über die unterschiedlichen Felder zugänglich sind. Ziel ist, eine Spielstrategie zu finden, die am schnellsten zu einem langfristigen Maximum des Zielwertes führt (im Falle des Unternehmens also der Geldeinheiten). Das Spiel kann jederzeit unterbrochen werden, es endet spätestens sobald alle Spieler die Voraussetzungen für den langfristigen Erfolg errungen haben. Mit ASiGo kommt eine Web-Plattform zum Einsatz, die in einem ersten Schritt speziell IfU Key-Konzept-basierte Planspiele als Browserspiele umsetzt – sich grundsätzlich aber auch zur Aufnahme anderer Planspielkonzepte eignet. Zentraler Gedanke hinter ASiGo ist, erprobte Planspielkonzepte bei geringem Aufwand der Vermittlung jedes Wissenskontexts zugänglich zu machen. Vor dieser Zielstellung lieferte die Situationsanalyse des Projekts drei wesentliche Herausforderungen:

- Ein Vorgehensmodell für das Entwickeln Key-basierter Planspiele
- Eine Web-Plattform für das Bereitstellen Key-basierter Planspiele
- Software-Hilfselemente für Key-basierte Planspiele als Browserspiel.

Im Folgenden wird primär auf das im Zuge von ASiGo entwickelte Vorgehensmodell eingegangen. Die technischen Aspekte der Web-Plattform und der Browserspielfunktionen, die einen Einfluss auf die Planspielentwicklung hatten, werden in darauffolgenden Abschnitten behandelt. Vorgehensmodell für IfU Key-Konzept Planspiele Beim Entwurf neuer Key-Planspielinhalte gilt es, die verschiedenen Spielelemente des IfU Key-Konzepts inhaltlich so auszugestalten, dass sie den gewünschten Lehr-Kontext optimal vermitteln. Um auch diesen Teil effizient zu realisieren, bedarf es eines Vorgehensmodells, das das Portieren des Key-Konzepts auf andere Wissenskontexte qualitativ sicherstellt. Dieses Modell stellt somit eine Spezifizierung des allgemeinen Vorgehensmodells zum Entwurf von Planspielen dar [Haf99]. Im Rahmen von ASiGo wurde folgendes Vorgehensmodell entwickelt (Abb. 2):

2.1 Wissenskontext

Inhalt/Methode: Die Thematik/der Lehr-Kontext des Spiels wird im Fall der Anwendung des IfU-Key Konzepts auf eine Vorlesung von dieser vorgegeben. Beispiel PM-Key: Projektmanagement in physiknahen Arbeitsumfeldern

2.2 Key-Fokus

Inhalt: Ausgangspunkt des IfU Key-Konzept ist dessen Lehr- und Lernfokus. Der erste Schritt nach dem Festlegen des Themas ist daher, dessen zentrale Herausforderungen zu beschreiben. Damit einher geht das Definieren der einzelnen Wissensfelder, die als Unterthemen des Lehr-Kontexts durch das Planspiel abgedeckt werden. Aufbauend auf diesen Informationen werden die zu den Herausforderungen gehörigen Lösungswege eingegrenzt. Die Lösungswege stellen im Key-basierten Planspiel den Schlüssel zum Spielerfolg und damit die zentrale Botschaft dar. An dieser Stelle kann bereits einzelnes Fakten- oder Verständniswissen spezifiziert werden, das Einzug in das Spiel finden soll. Methode: Im Falle der Anwendung des Key-Konzpets auf eine Vorlesung bietet sich die moderierte Befragung von Dozenten und Übungsleitern in Kombination mit der Analyse bestehender Unterrichtsmaterialien und Sekundärliteratur an. Sollte eine sehr umfangreiche Informationslage bestehen, empfiehlt sich eine Prioritätenliste der unterschiedlichen Inhalte – z. B. mittels Tabellenkalkulation. Beispiel PM-Key: Der PM-Key-Fokus ergibt sich aus Herausforderungen, Wissensfeldern, Lösungswegen und Wissensbausteinen des Managements experimenteller Forschungsprojekte. Diese Frage wurde abschließend in Befragungen (Workshops) von zwei unterschiedlichen Wissensträgergruppen spezifiziert.

2.3 Key Rahmengeschichte & Abteilungen

Inhalt: Die Rahmengeschichte gibt die Simulationsumgebung des Spiels vor. Aus ihr ergeben sich die Rollen sowie die Systemumwelt [Ker03]. Da die Rollen in Key-

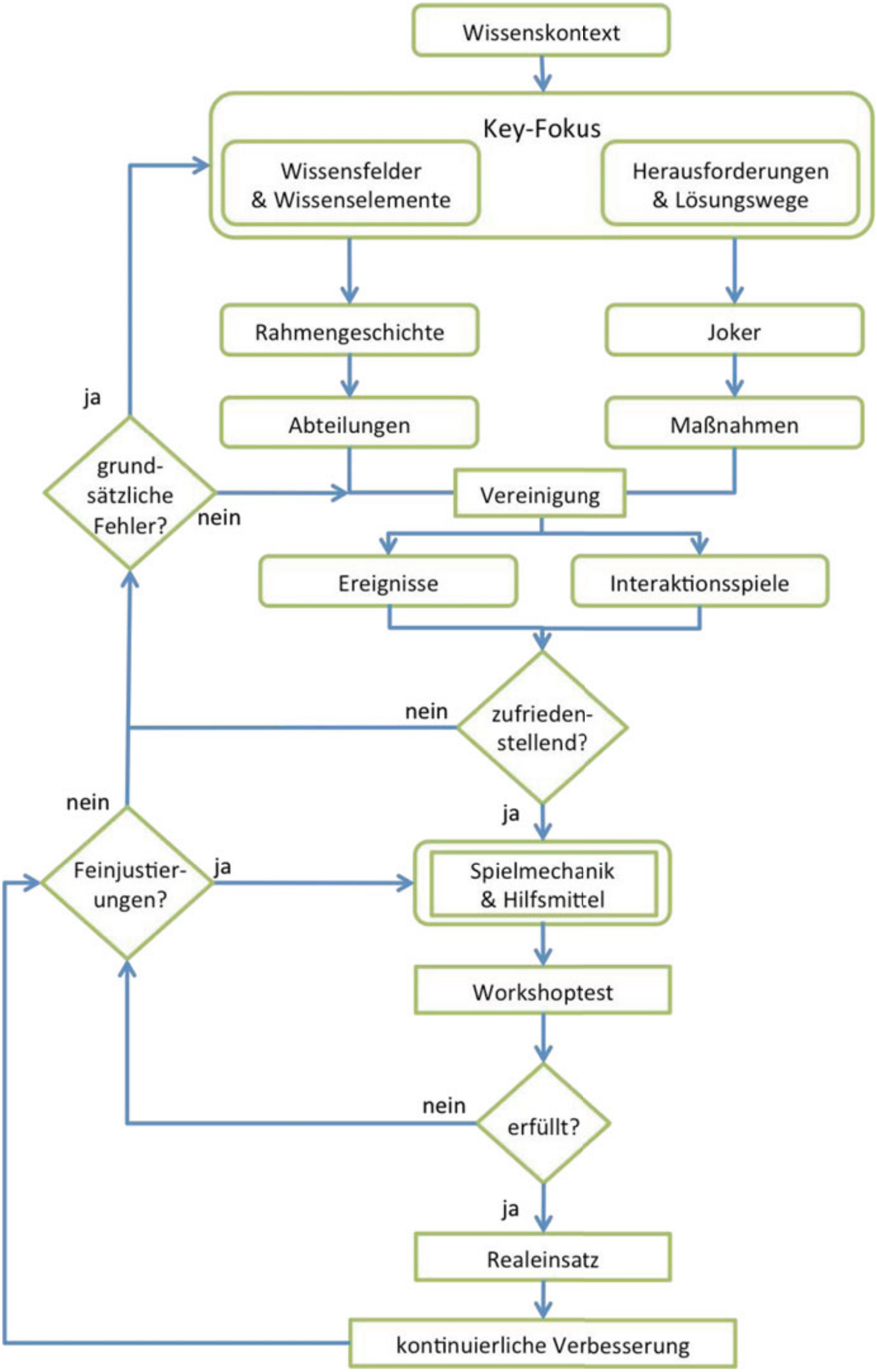

Abb. 2 Vorgehensmodell zur Entwicklung von IfU Key-Konzept basierten Planspielen

Planspielen weitestgehend Unternehmenseinheiten entsprechen, werden diese Abteilungen genannt. Im Standardfall wird von einer Anzahl von fünf Abteilungen, also auch einer Idealbesetzung mit fünf Spielern pro Gruppe ausgegangen. Dies ist ein Kompromiss aus dem Bestreben, der Spielgruppe möglichst viele Eindrücke der simulierten Umwelt zu bereiten und den Aufwand der Planspielerstellung zu begrenzen, da jede zusätzliche Abteilung das Schaffen eigener Ereignisse erfordert (siehe Abschn. 4). Aus der Rahmengeschichte leiten sich ebenfalls die zu maximierende Zielgröße (z. B. Geldeinheiten) sowie die inhaltliche Repräsentation der Spielsteine ab. Methode: Zur Findung von Rahmengeschichte und Abteilungen sind Gruppenbefragungen, bzw. darin sämtliche Kreativitätstechniken geeignet (z. B. Brainstorming, Kartenabfrage, etc.). Die Kriterien sind:

- Interessen der Zielgruppe für eine maximale Spielmotivation
- Menge verfügbarer Informationen für eine reiche, authentische Simulation
- Relevanz der Kombination aus Abteilung und Rahmengeschichte für das Verständnis des zu vermittelnden Themas.

Beispiel PM-Key: Als Rahmengeschichte dient das Umfeld des weltgrößten Teilchenbeschleunigers Large Hadron Collider (LHC) am europäischen Kernforschungszentrum CERN in Genf. Die „Abteilungen“ spiegeln die wesentlichen Aufgaben und Sichtweisen wider, die in diesem Projektumfeld anzutreffen sind. Sie lauten: CERN-Rat, CERN-Direktorat, CMS-Management (CMS ist ein LHC-angegliedertes Großexperiment), Industriepartner, RWTH-Arbeitskreis. Da auch der Erfolg von Projektmanagement sich schlussendlich in monetären Einheiten ausdrückt, ist die PM-Key Zielgröße Geldeinheiten; die Spielsteine repräsentieren Arbeitspakete, welche mit maximalem Erfolg durch die Abteilungen zu bringen sind.

2.4 Joker & Maßnahmen

Inhalt: Die Funktion dieser Spielelemente ist, die zentralen Herausforderungen des Themas und deren wesentliche Lösungswege herauszustellen. Die Joker stellen dabei Errungenschaften dar, die das Problem lösen und die mittels der Maßnahmen verdient werden können. Das gezielte Durchführen und der daraus resultierende Erwerb der jeweils benötigten Joker ist somit die langfristige Siegstrategie in Key-Planspielen. Der daraus resultierende Spielerfolg verknüpft die Inhalte der Joker und der Maßnahmen mit der Lösung der Herausforderungen des durch das Spiel beschriebenen Themengebiets. Die Anzahl der für den langfristigen Erfolg nötigen Errungenschaften bestimmt auch die Anzahl der nötigen Runden bis Spielende. Im Falle von drei unterschiedlichen Jokerklassen sind in der Brettspielvariante im Durchschnitt 15–20 Spielrunden nötig bis der erste Spieler sämtliche Voraussetzungen für nachhaltigen Erfolg errungen hat. Methode: Wegen der Auswirkung der Joker auf die Spieldauer empfiehlt sich, die vom Planspiel behandelten Herausforderungen und Lösungswege in drei Klassen zu unterteilen. Für diesen Prozess sind ebenfalls Dokumentenanalyse und Gruppenbefragungen geeignet. Kriterium ist, dass die gefundenen Klassen das vom Planspiel behandelte Problemspektrum hinreichend vollständig und trennscharf abdecken. Die gesuchten Maßnahmen ergeben sich aus diesen Klassen und spiegeln die in der Lehrveranstaltung vermittelten Kompetenzen wider. Beispiel PM-Key: Die Jokerkategorien spiegeln die für die Qualität des Projektmanagements zentralen Kriterien Qualität des Managements (Management), Qualität des Teamgefüges (Team) und Qualität der Prozesse (Prozess) wider. Das Key-Element der Maßnahmen bildet sich daher aus besonders erfolgreichen Projektmanagementmethoden, die diesen Kriterien zuzuordnen sind.

2.5 Ereignisse & Interaktionsspiele

Inhalt: Während des Spiels sind neben dem Würfel primär diese beiden Elemente für das dynamische Moment verantwortlich. Ausgelöst durch das Betreten der entsprechenden Spielfelder simulieren Ereignisse in zufälliger Abfolge mögliche bis typische Wirkungen der Rahmengeschichte oder der Abteilungen. Sie können dem Spieler Entscheidungen abverlangen und abhängig davon entsprechende Konsequenzen nach sich ziehen. Sie können sich nur auf eine Abteilung oder auch auf die gesamte Spielgruppe auswirken. Abteilungsübergreifende Ereignisse ermöglichen somit eine Interaktion zwischen den Spielern. Zwei oder mehr Spieler müssen hier gemeinsam eine Aufgabe lösen, um eine der Errungenschaften (Joker) aufzuwerten. Methode: Die Ereignisse im IfU Key-Konzept tragen die wesentliche Verantwortung für die Authentizität des Planspiels. Als Grundlage für deren Entwurf eignen sich daher Erfahrungsberichte realer Ereignisse, die die Rahmengeschichte und die Abteilungen betreffen. Diese Informationen lassen sich effizient über Dokumentenanalyse und Experteninterviews erheben. Alle wesentlichen Herausforderungen des Planspielthemas sollten sich in mindestens einem Ereignis wiederfinden. Beispiel PM-Key: Ein beispielhaftes Ereignis mit Entscheidungsmöglichkeit ist in Abb. 3 zu sehen. Für die Interaktionsspiele sind prüfungsähnliche Multiple-Choice-Fragen eingebaut, die alle Teilnehmer eines Interaktionspiels separat korrekt beantworten müssen. Bei Misserfolg werden die betroffenen Joker der Spieler nicht aufgewertet, sodass es eines neuen Versuchs bedarf, der erneut Zeit und Geldeinheiten kostet.

2.6 Spielmechanik & Hilfsmittel

Inhalt: Auch wenn das IfU Key-Konzept bereits die wesentlichen Spielregeln und Mechanismen vorgibt, ergeben die verbleibenden Freiheitsgrade noch weitreichende Möglichkeiten der Fein- und Grobjustierung der Spielmechanik. Einfachstes Beispiel hierfür sind die Strafen und Belohnungen im Spiel. Strafen und Belohnungen wirken sich negativ bzw. positiv auf die Zielgröße des Spiels oder die Position oder Bewegungsfreiheit der Spielsteine aus. Sie sind das Resultat der Handlungen der Spielrunde und der Reaktionen der Spieler auf Ereignisse. Ähnlich wie mit der Spielmechanik verhält es sich auch mit den softwareseitigen Hilfsmitteln, die durch ASiGo vorgegeben sind. Auch diese können eingesetzt werden, um den Spieleffekt zu optimieren. Methode: Für das Optimieren von Spielmechanik und Hilfsmitteln sind Vergleiche mit etablierten Key-basierten Planspielen geeignet. Anhand von Testspielen erfolgt die Feinabstimmung, d. h. das justieren von Höhe und Häufigkeit der Strafen und Belohnungen für die Handlungen und Reaktionen der Spieler. Insbesondere ist an dieser Stelle zu beachten, dass das Implementieren von Erfolgserlebnissen außerhalb der intendierten Siegstrategie (Erwerb der Joker) großen Einfluss auf die von den Spielern benötigte Zeit zum Finden dieser Strategie hat. Die Hilfsmittel müssen insbesondere auf die Informations- und Kommunikationsanforderungen des gewünschten Umfangs der Interaktion zwischen den Spielern angepasst werden. Beispiel PM-Key: Die Feinabstimmung hatte zur Folge, dass die PM-Key Ereignisse fast ausschließlich negative Effekte nach sich ziehen. D. h. die Konsequenzen der Ereignisse variieren je nach Güte der Handlungen des Spielers lediglich zwischen großen und geringen Abzügen an Geldeinheiten und Spielfeldpositionen. Belohnungen erfolgen nur durch das Fertigstellen von Arbeitspaketen; Joker schützen vor den Strafen. Auf Basis dieser Spieleinstellung ist gewährleistet, dass die Spieler in minimaler Zeit die langfristige Spielstrategie aufsuchen – also die intendierte Botschaft des Spiels erfahren. Dies vermittelt zum einen, dass unvorhergesehene Ereignisse im realen Projektalltag meist negative Konsequenzen nach sich ziehen, zum anderen, dass selbst die besten Lösungen, die kurzfristig für jene Ereignisse gefunden werden, immer noch einen kurzfristigen Mehraufwand bedeuten. Für das Interaktionsspiel wurde ein Interface für Multiple-Choice-Fragen implementiert.

3 Grundsätzliches zum Vorgehensmodell

Auch wenn die Nummerierung der Erläuterungen (von Abschn. 2.1 Wissenskontext bis Abschn. 2.6 Spielmechanik & Hilfsmittel) sowie die Richtung der Pfeile im Vorgehensmodell (Abb. 2) suggerieren, dass das Ausarbeiten der IfU Key-Konzept Elemente sequenziell abläuft, handelt es sich dabei tatsächlich um einen iterativen Prozess: Welche Abteilungen sinnvoll auszuwählen sind, hängt zum Beispiel auch davon ab, ob sich für diese auch interessante Ereignisse von ausreichender Authentizität entwerfen lassen. Die erzielte Qualität der nachfolgenden Spielelemente (z. B. Maßnahmen) ist somit immer auch Qualitätsmerkmal für die Eignung der zu Grunde liegenden übergeordneten Elemente (z. B. Joker-Kategorien). Eine zu geringe Qualität der Folgelemente bedingt also im Zweifelsfall das Anpassen der Vorgängerelemente. Sollte ein Key-Planspiel auch nach einigen Iterationsschleifen und Feinjustierungen noch keinen nennenswerten Erfolg zeigen, muss im Zweifelsfall sein Fokus grundsätzlich überdacht werden. Für das zielgerichtete Entwickeln eines Key-basierten Planspiels ist wichtig zu verstehen, dass dessen inhaltliche Gestaltung von zwei Gestaltungsperspektiven geprägt wird:

1. Mit welchem Kontext sollen die Spieler konfrontiert werden?
2. Was ist die intendierte Botschaft, die den Spielern in der Realität als Handlungsempfehlung dienen soll?

Während der gewünschte Kontext durch die Rahmengeschichte und die Abteilungen konkretisiert wird, findet das Vermitteln der intendierten Botschaft oder des Lehrinhalts mittels der Spielelemente Joker & Maßnahmen statt. Indem die Inhalte der Maßnahmen mit der Belohnung durch die Joker verknüpft werden, erzeugt das Spiel eine Assoziation zwischen erfolgreicher Spielstrategie und erfolgreichem Verhalten in der vom Spiel simulierten Realität. In den Ereignissen werden Kontext und intendierte Botschaft schließlich vereint. In ihnen wird beim Spieler die Assoziation zwischen der Rahmengeschichte (PM-Key: Forschungsprojekt) und den Wirkungsmechanismen der Simulation (PM-Key: Projektmanagement-relevante Kompetenzen schulen) hergestellt. Ein Beispiel für ein solches Ereignis ist auf dem Bildschirmfoto des fertigen Browserspiels zu sehen (Abb. 3).

4 ASiGo – Plattform für Browser-Planspiele

Aufgabe der Plattform ASiGo ist im ersten Schritt, Browserplanspiele nach dem IfU Key-Konzept so zu unterstützen, sodass deren Lehr- und Lernziele maximal umgesetzt werden. In diesem Zusammenhang ist wichtig anzumerken, dass das IfU Key-Konzept ursprünglich für Brettspiele entwickelt wurde. Die offensichtliche Herausforderung für die Softwareumsetzung besteht also darin, die gegenüber der Brettspielumgebung fehlenden Eigenschaften der Browserspielumgebung (z. B. fehlender Zwang zur Beschäftigung mit dem Spiel) mit Hilfe technischer Hilfsmittel auszugleichen und die Vorteile der Softwarewelt maximal zu nutzen [Arn08, Pre03]. Das Problem der nicht direkten Kommunikation zwischen den Gruppenmitgliedern wird beispielsweise mittels einer in die Plattform integrierten Textkommunikationsmöglichkeit – dem Teamforum (Abb. 3 oben rechts) – angegangen. Die Einschränkung der Kommunikation auf E-Mail & Co. bzw. auf zuvor vereinbarte Treffen wird zudem als Realitäts-fördernde Eigenschaft der Softwarelösung genutzt.

Abbildung 3 zeigt ein Bildschirmfoto der fertigen Plattform mit PM-Key im Spielbetrieb. Zu sehen ist darauf das Spielfeld und die Oberfläche eines Testspielers, dem die Abteilung CERN-Rat zugelost wurde und der nach 46 Spielrunden 14.000 Geldeinheiten, sowie einen vollständigen und aufgewerteten Joker besitzt. Die Spielsteine sind als rote Kreise auf den Feldern 6, 13 und 14 (im Uhrzeigersinn) zu erkennen. Durch den ersten dieser Steine wurde ein abteilungsspezifisches Ereignis ausgelöst, auf das der Spieler auf drei unterschiedliche Weisen antworten kann. Wenn diese Entscheidung getroffen wurde, kann in der gleichen Runde noch einer der drei Steine um zwei Felder (Ziffer in der Mitte des Spielbretts) in Richtung Ziel (letztes Feld auf der rechten Seite) gezogen werden, was wiederum Ereignisse auslösen kann.

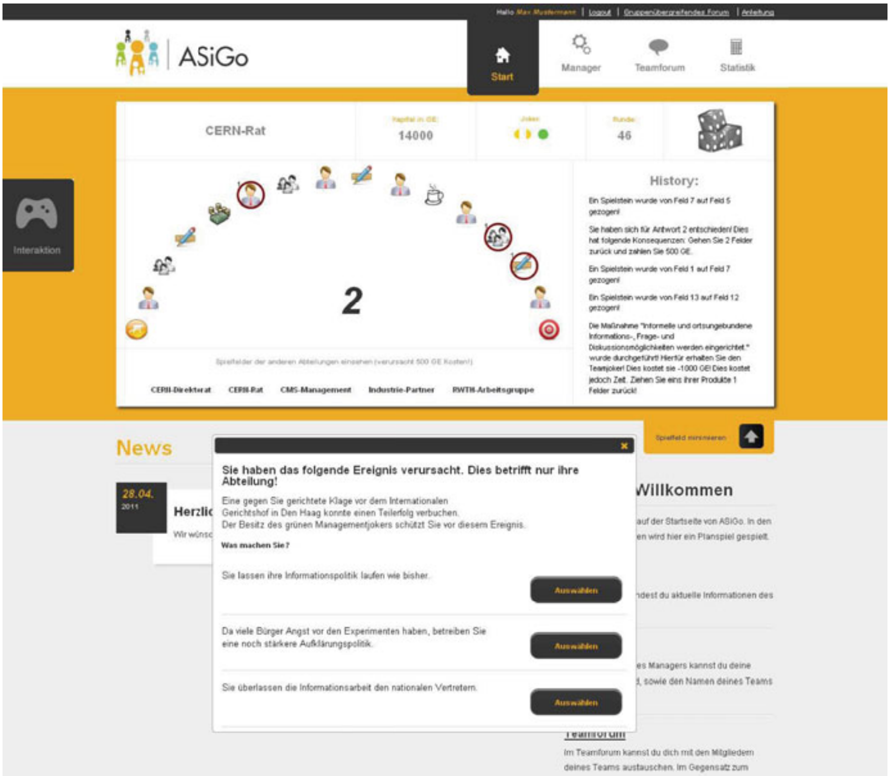

Abb. 3 Bildschirmfoto der Plattform ASiGo mit dem PM-Key Planspiel in Aktion

5 Die Technik hinter ASiGo

Technisch wurde das Online-Planspiel mit Hilfe des Architekturmuster Model-View-Controller (MVC) aufgebaut, das seit seiner Einführung in den 1970er Jahren zum Standard für den Grobentwurf komplexer Softwaresysteme geworden ist [BY10]. Das MVC Konzept ermöglicht insbesondere das Anpassen von Benutzeroberflächen bei geringem Aufwand und erfüllt somit eine der zentralen Anforderungen der Plattform. Auf Serverseite wurde ASiGo mit der Skriptsprache PHP geschrieben. Der PHP-Code generiert die im Browser angezeigten HTML-Seiten. Um auch an dieser Stelle möglichst effizient zu arbeiten, wurde das Framework CakePHP genutzt, das sowohl das Architekturmuster MVC bereits implementiert als auch weitere nützliche Funktionalitäten mitbringt. Die Parameter eines spezifischen Planspiels wie z. B. PM-Key (Spielregeln, Spielinformationen, Beschreibungen und Auswirkungen von Spielereignissen) werden wiederum in XML-Dateien festgehalten, sodass sich Änderungen oder auch gänzlich neue Inhalte für Spiele nach dem IfU Key-Konzept sehr leicht einpflegen lassen.

6 Ergebnisse des PM-Key Einsatzes

Nach vorherigen Tests als Brettspiel- und als Browserspielvariante in Workshop Settings mit jeweils fünf Spielern wurde PM-Key über die Plattform ASiGo schließlich im realen Einsatzszenario mit 53 Studierenden der PMP Vorlesung über einen Zeitraum von drei Wochen getestet. Die Studierenden konnten dabei pro Tag einen Spielzug durchführen und versuchen, den Gesamtgeldbestand ihrer Gruppe bis zu einem Stichtag nach 15 Spieltagen zu maximieren. Um die Wirkung von PM-Key auf die Projektmanagementkompetenzen der Studierenden evaluieren zu können, wurden von den Spielern vorher und nachher Fragebögen beantwortet. Da das Primärziel von PM-Key im Schaffen von Bewusstsein für die Herausforderungen des Projektmanagements lag, waren die Fragen speziell auf dieses Kriterium hin ausgerichtet. Beispiel: „Gelegentliche Fehler in der Programmierung sind kein Grund, aufwändige Maßnahmen zu ergreifen.“ (Fünf Ausprägungen von voller bis keiner Zustimmung) Nicht gestellt wurden hingegen Fragen zu Projektmanagementfachwissen. An den freiwilligen Befragungen nahmen in der ersten Runde 53, in der zweiten Runde 35 Spieler teil. Die ersten Auswertungen deuten dabei auf einen leichten Anstieg des Problembewusstseins für Projektmanagementherausforderungen hin. Auf Grund der mangelnden Eindeutigkeit der Ergebnisse und der komplexen Störgrößen der Befragung (laufende Vorlesung, Klausurvorbereitung), müssen weitere Untersuchungen ergeben, welchen Lerneffekt das Planspiel in diesem Setting erzeugt hat. Aus den Kommentaren der Evaluation der PMP Vorlesung geht hervor, dass PM-Key die Auseinandersetzung mit den Problemstellungen und Inhalten des Projektmanagements gefördert hat. Für das Auffinden von Schwächen in Inhalten, Spielmechanik und Hilfsmitteln des Gesamtkonstrukts „PM-Key als Browserspiel“ eignet sich der Vergleich der Beobachtungen der beiden Workshoptests – einmal in Brettspiel- und einmal in Browserspielversion. Prägend sind hier zwei Beobachtungen:

- Die Spieler einer Gruppe des Browserspiels erkundigen sich trotz uneingeschränkter Austauschmöglichkeiten im Workshop Setting nur selten über die Spielstände und Erfahrungen ihrer Mitspieler. Die Brettspielvariante zwingt hingegen jeden Teilnehmer, die Aktionen und Ereignisse der anderen mitzuerleben.
- Die Spieler nehmen Strafzahlungen deutlich leichter hin als in der Brettspielversion. In letzterem Einsatzfall lässt sich beobachten, wie jeder Verlust eines Spielgeldscheins den Spielern „schmerzt“. In der Browserspielvariante, die lediglich den Kontostand numerisch ausweist, ist dieser Effekt deutlich geringer ausgeprägt.

Vor dem Einsatz von PM-Key in der Vorlesung wurden Maßnahmen ergriffen, um diese Effekte zu lindern. Da zu jenem Zeitpunkt eine grundlegende Überarbeitung jedoch nicht mehr möglich war, muss davon ausgegangen werden, dass die oben beschriebenen Effekte im Real-Test der PMP Veranstaltung nicht vollständig eliminiert werden konnten. Vergleichende Analysen des durchschnittlichen Spielverhaltens beider Szenarien legen dies ebenfalls nahe.

7 Fazit und Ausblick

Im Zuge des Projekts ASiGo wurde ein Vorgehensmodell entwickelt, um beliebige Lehrinhalte mittels eines Planspiels nach dem IfU Key-Konzept zu vermitteln. Das Vorgehensmodell ermöglicht das gesicherte und gleichzeitig schlanke Erstellen von Planspielen, die themenspezifisches Problembewusstsein, Lösungswege sowie Fakten- und Verständniswissen vermitteln. Das für Brettplanspiele entwickelte Konzept wurde erfolgreich und mit einem Aufwand von ca. zwei Personenmonaten auf die Thematik „Projektmanagement für Physiker“ angewendet. Das Projektziel einer modernen, nutzerfreundlichen und leicht anzupassenden Web-Plattform für Planspiele nach dem IfU Key-Konzept wurde mittels des Programmierframeworks CakePHP erzielt. Ein großer Teil des für PM-Key benötigten Codes konnte so automatisch generiert werden. Die strikte CakePHP Struktur hat sich zudem bewährt, um die Entwicklungsarbeit an der Plattform flexibel von unterschiedlichen Programmierern durchführen lassen zu können. Entsprechend des Vorgehensmodells für IfU-Key Konzept basierte Browserplanspiele tritt PM-Key nun in weitere Iterationsschleifen eines kontinuierlichen Verbesserungsprozesses ein. Die Maßnahmen zur Verbesserung der Planspielwirkung beginnen im Bereich der Hilfsmittel und der Spielmechanik:

- Deutliche Vereinfachung der Kommunikations- und Informationsmöglichkeiten zwischen den Mitgliedern einer Gruppe.
- Anpassung der Spielmechanik in Richtung mehr Spannung und mehr verdiente Erfolgsmomente.

Geplant ist u. a., die Entwicklung der Abteilung des einzelnen Spielers sowie die der Mitspieler frei zugänglich und mit mehr dramatischem Effekt darzustellen – z. B. in Form einer Art „Lebensenergieanzeige“ wie sie aus Computerspielen bekannt ist. Zudem könnten Wasserstandsmeldungen zur Konkurrenzfähigkeit der eigenen Gruppe im Vergleich zu den anderen Gruppen für mehr Interesse am Spiel sorgen. Auch die Ereignisse von PM-Key könnten in diesem Zuge verändert werden, um die Auseinandersetzung der Spieler mit deren Inhalten zu fördern. Sollte das ausgegebene Ziel erreicht werden, Planspiele mit Hilfe des Vorgehensmodells und der Plattform ASiGo mit geringem Aufwand für neue Lehrinhalte zu entwickeln und einzusetzen, könnte sich dieses Mittel ebenfalls eignen, ein speziell an der RWTH Aachen in der Fakultät für Maschinenwesen verbreitetes Problem zu lindern: Hier stellen sogenannte große Hörerzahlen die Dozenten vor die spezielle Herausforderung, 700 bis 1400 Studierende in ihre Vorlesungen und Übungen zu involvieren [STB+11]. Dank sehr guter Skalierungseigenschaften haben Software-basierte Planspiele hier das Potential die Inhaltsvermittlung bei geringfügig steigendem Aufwand zu verbessern.

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Problem Based Learning of Object-Oriented Programming with LEGO Mindstorms NXT and LeJOS

Daniel Ewert, Daniel Schilberg, Sabina Jeschke

Abstract Problem based learning has proved to be a powerful educational approach to successful and effective teaching. Experiences worldwide have shown the attraction of robotics and the improved motivation of students dealing with robots. Problem based learning (PBL) as well as robotics are usually applied when dealing with smaller groups of students. However, in the first year of study student numbers of more than 1000 are a common phenomenon for lectures in mechanical engineering. This paper introduces a setup for teaching object-oriented programming based on programming LEGO Mindstorms NXT robots for large scaled groups. The huge number of students – up to 1500 students per year – to be dealt with presents a special challenge, due to resource limitations as well as technical aspects. We therefore present a problem based learning approach based on a fixed robot setup with pre-build robot models.

Key words: Education in Mechanical Engineering, Blended Learning, LEGO Mindstorms NXT, LeJOS

1 Introduction

1.1 Overview

The Institute of Information Management in Mechanical Engineering (IMA) of the RWTH Aachen University lectures Computer Science on Mechanical Engineering [HGS09]. This lecture is currently being refactored from a general approach covering a broad range of computer science related topics to a new approach concentrating on software engineering. This renovation also affects the affiliated labo-

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ratory. Here, the students are meant to gather first experience in the fundamentals of object-oriented programming. Student evaluations have shown a demand for more self-contained programming as well as "hands-on" tasks. Therefore, the new laboratory aims on palpable tasks the students can carry out completely on their own.

Previous smaller laboratories and experiences worldwide have shown the attraction of robotics and the improved motivation of students dealing with robots [HHJ10, HJNP09]. Therefore, the laboratory is based on programming LEGO Mindstorms NXT robots which has proven to be a suitable teaching instrument [Kla02] with Java using the LeJOS platform [Sol01]. The laboratory is attended by up to 1500 students each year. The students come from different programs: Approximately 80 % of the students study Mechanical Engineering in the second semester, 15 % study industrial engineering and management in their fourth semester. The remainder is distributed over different smaller programs.

2 Organizational and Technical Challenges

Experiences from smaller robot courses as well as the student laboratory Roboscope [HHJP10] have shown the optimal size for a team working together on one robot and one workstation is two students. This limitation does not necessarily apply to other robot courses focussing on a construction of a robot. However, the focus of this laboratory is the programming of the robot. Two students can sit together at one workstation and work on the same problem using the technique of pair programming [CW00]. For more than two students this technique is not applicable simply due to limitations in access to the workstation. Therefore, since these additional students would have to work at another workstation, the given task would have to be separable in distinct and comparable subtasks to avoid the risk of unequal workloads or even complete exclusion of single students.

The laboratory takes place in the so called ARPA (see Fig. 1), which is the largest computer pool of the RWTH Aachen University equipped with approximately 200 workstations.

These limitations in space restrict the maximal number of students that can attend the laboratory in parallel to 200 students which then work with 100 Mindstorms NXT robots. Due to increased motivation, it would be desirable to have each team construct its own robot. However, this would result in a demand for 750 robot construction kits, since the robots cannot be dismounted and reassembled in each lesson. Therefore the laboratory is based on a standardized and preassembled robot model depicted in Fig. 2. This allows several student teams to work with the same robot in consecutive courses and improves the comparability of the student's achievements.

The decision to work with the stationary model of a robot arm is also motivated by another technical issue: To allow students to debug their code, there must be ways to read the programs output during execution. For a mobile robot one must rely on a Bluetooth connection between PC and robot. However, with 100 Mindstorms which have to connect to 100 PCs in close vicinity to each other and a probably huge number of other Bluetooth devices as mobiles, the bandwidth of the connec-

Fig. 1 The ARPA computer pool

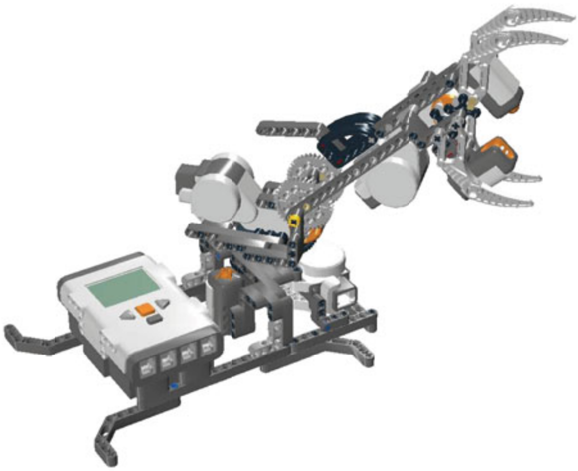

Fig. 2 Model of the LEGO Mindstorms NXT robot used in the laboratory

tions is reduced too much to make any use of it. Additionally the management of these connections would prove to be too error-prone and would additionally be very susceptible to sabotage by students. These problems can be avoided by utilizing a static setup. Here, debugging or uploading code to the robot can be done using a more reliable usb cable connection. Another advantage is the reduced place requirement since all testing can be done directly at the student's workstation without the need for any test areas mobile robots would rely on.

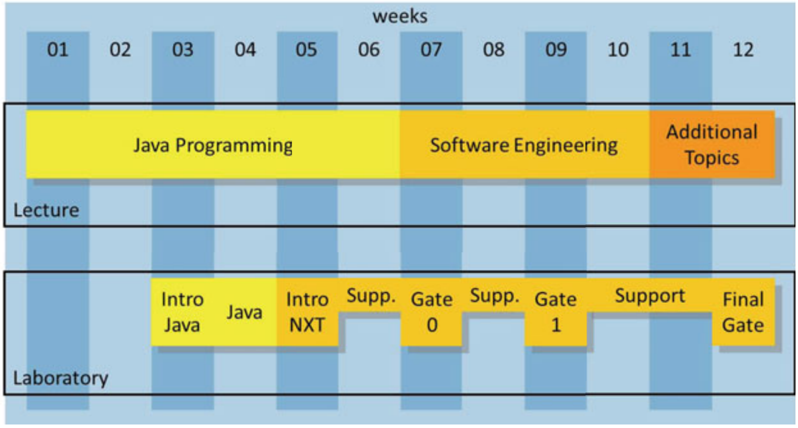

Fig. 3 Schedule of lecture and laboratory

3 Schedule

The laboratory consists of 10 weekly units, each with a duration of 135 minutes. It is divided in two parts with regard to the contents (see Fig. 3):

- The first part – the first two units – deals with pure Java programming. It aims on teaching the first basic principles and introducing the working environment and the tool chain. Since most students have virtually no programming experience, the "pure Java" part is thoroughly organized and relies on PBL on a lesser extent as the second part, to avoid disorientation and subsequently demotivation of the students. Out of the same reason we abstain from incorporating LeJOS here to diminish irritation due to an overload of new tools and techniques.
- In the second part the students program their Mindstorms NXT robot to solve a given task. Here, the students already have gained experience in Java and their work environment. Therefore, this part encourages the students to self-contained program their own solutions, and so increases the student's motivation by allowing them to identify with their work. Here, the laboratory follows the principles of PBL. The students are presented with a task that solely defines the expected functionality of the robot. It contains no information regarding how this functionality is to be achieved.

The laboratory starts delayed to the lecture, so that the Java part can build up on the theoretic input from the first two lecture units. The advanced topics of the lecture regarding Software Engineering are timed in a way that students can (but not have to) make immediate use of it when programming their robots.

4 Setup of the Laboratory

4.1 Pure Java

The first part of the lecture introduces the students to the basic principles of Java programming. As a first step, the students learn to use the Java compiler and start their programs, both using the command line and using the Integrated Development Environment (IDE) Eclipse [ecl]. In a second step, they receive a number of smaller tasks which can be solved without more complex concepts as object orientation. These tasks are the implementation of mathematical functions as:

- Calculation of the faculty of a number entered by the user
- Exponentiation
- Testing if a entered number is prime
- Output of all prime numbers below an entered threshold.

To allow the students to focus on the actual program functionality, the more complex mechanism of reading user input is encapsulated in a helper library which provides simple static methods to read primitive datatypes as integers, chars and doubles from the standard input.

The intention of these tasks is on one hand to introduce variables, value assignment and simple mathematical operations as well as techniques of structured programming as loops and conditions. On the other hand the small and simple tasks are meant to provide feelings of success in a very early stage of the laboratory. Evaluations of the previous laboratories [HGH07] showed that most students had strong prejudices against programming regarding complexity and usefulness in their later work and were consequently not motivated to learn programming at all. The simple setup used here is meant to reduce the experienced prejudices. The students write these small programs completely on their own without having to rely on existing frameworks or toolchains. All program functionality is a result of the students work. This experience is meant to make the students recognize programming as a useful and powerful tool instead of an abstract and theoretic method with no immediate use for themselves.

The following laboratory unit introduces the object-oriented aspects of Java. The task is to create a program that realizes matrix multiplication. The user enters the dimensions of the matrices to be multiplied as well as the single matrix entries. The program then outputs the result of the multiplication or an error message if the multiplication is not possible. In a first approach, the students solve this problem by relying entirely on procedural programming and arrays as data structures. As next task the students refactor their solution by incorporating a Matrix class, which encapsulates all functionality. The underlying intention is to demonstrate the benefit of following object-orientation. By comparing both variants of their multiplication programs the students can immediately observe the improvement in reusability and readability in their code. As a next step, the students are requested to implement an interlinked multiplication of more than two matrices. The easy realization of

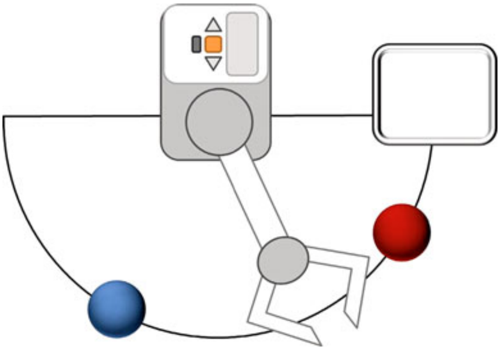

Fig. 4 Schematic of the robot setup

this task in the object-oriented approach intensifies the experienced usefulness of object-oriented programming when dealing with complexity in programs.

4.2 Mindstorms NXT Programming

4.2.1 Overall Goal

The second part of the laboratory is based on the principle of problem based learning. The students are requested to program a robotic gripper inspired by industrial robots. This resemblance to "real" robots is meant to result in higher acceptance from students of mechanical engineering.

The overall goal of the robot is to scan the surrounding area for coloured balls. The detected balls are then picked up and disposed in a box (see Fig. 4). For object detection the students can make use of the ultrasonic sensor, a light sensor and a touch sensor located within the gripper. The robot arm can be moved up and down or from left to right by directly controlling the corresponding motor. The third installed motor controls the gripper hand.

The students realize this goal during the remainder of the laboratory. However, to allow for tracking the progress and to give weaker students a chance to catch up, the overall goal is separated into four sections described below.

4.2.2 Introduction

In this unit the properties of the Mindstorms NXT robot are presented as well as the tools necessary to program the NXT. The laboratory makes use of the Eclipse IDE with a plugin for LeJOS [lej]. In this phase the students acquaint themselves with these tools. Therefore they can make use of minimal code examples provided within the support material. However, these examples do not aid in solving the tasks to fol-

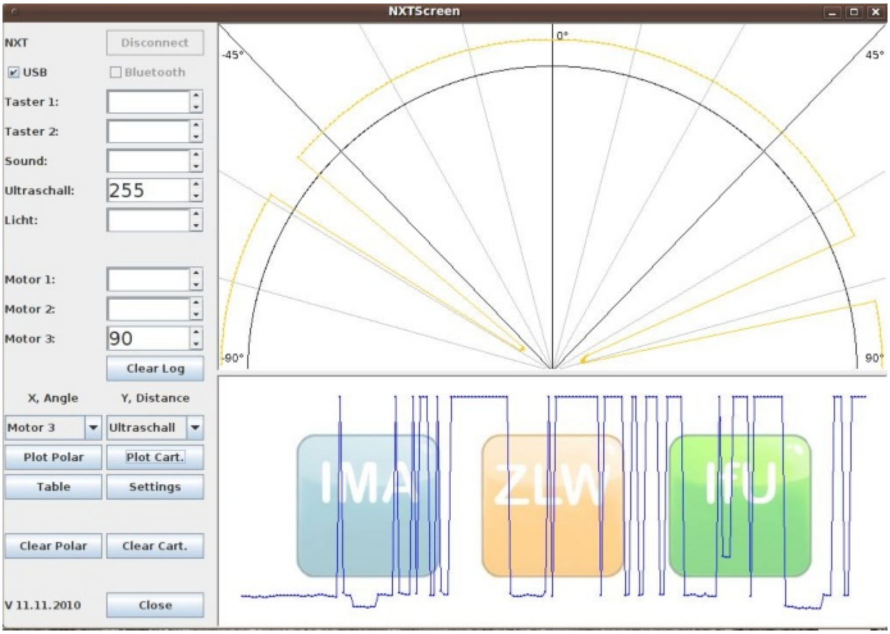

Fig. 5 Graphical User Interface to visualize sensor data

low, but demonstrate other capabilities of the Mindstorms NXT robot as displaying messages, make noises or similar. The studies are invited to experiment with these given code snippets.

4.2.3 Gate 0 – Teachbox

The students implement manual control for their robot. Using the buttons of the Mindstorms brick the goal is to move the robot arm as well as open and close the gripper. The focus of this gate is learning to control the robot's motors via the LeJOS API. Since this task does not rely on complex interpretation of sensor input, all robot actions emerge from the students program. The students again are meant to receive positive results very soon without frustration due to irreproducible robotic behaviour. The described task can be scaled in complexity to keep students with advanced programming skills motivated: Instead of querying the robot's buttons via simple loops, the student's program can also be based on the observer design pattern.

4.2.4 Gate 1 – Visualization of Sensor Readings

In the third section the students focus on accessing and interpreting data of the ultrasonic sensor. Therefore, they can make use of a provided GUI (see Fig. 5) to visualize the sensor readings in context to the robots position. The students are meant to discuss ways to detect objects as well as suppress noise or failed readings as a preparation for the final section

4.2.5 Final Gate – Detect and Pick Up

Based on the results of the foregoing sections, the students now realize the main task. The robot is meant to scan its surroundings. Afterwards it autonomously picks up all detected objects (balls) and discards them into a container. Advanced students can here make use of the light sensor to distinguish objects and handle them differently, e.g. sort them by colour or place them in different containers. The main challenge is to detect the exact position of an object so that it can be gripped successfully. The students must test various strategies and parameters to find a good solution.

As mentioned above, this second part follows the PBL strategy. In all phases of the second part, the students are absolutely free in how they achieve the desired functionality. After each gate a sample solution is presented and discussed, so that weaker students have a chance to keep up. Between the gates the laboratory abstains from ex-cathedra teaching. The students can freely work for themselves and have access to the robots independently of the official laboratory dates. However, they can make use of comprehensive support material as well as assisting staff present during support periods.

5 Summary

To answer the demand of students for self-contained and applicatory tasks in a programming laboratory and at the same time be able to deal with a huge number of students attending this laboratory without risking to demotivate students, we developed a bipartite laboratory based on programming LEGO Mindstorms NXT robots. By utilization of a fixed model of a 3-axis robot arm we react to resource limitations in space as well as the number of necessary robot kits. This setup allows also allows to abstain from error-prone techniques as wireless Bluetooth to debug the robot. The students can work with a maximized degree of freedom, however, to give weaker students a chance to keep up, the overall task is staged in three gates. We believe the presented setup to be a suitable laboratory to rouse and keep the student's motivation to engage themselves in programming even in large groups. The next steps in improving the presented laboratory are to allow for a better scaling of the difficulty of the given tasks to keep students with different grades of programming skills equally motivated. We intend to develop additional scenarios with varying complexity from which the students then can choose the scenario which matches their abilities.

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Hands on Robotics – Concept of a Student Laboratory on the Basis of an Experience-Oriented Learning Model

Alan Hansen, Frank Hees, Sabina Jeschke

Abstract At the ZLW/IMA (Center for Learning and Knowledge Management/Institute of Information Management in Mechanical Engineering) of the RWTH Aachen University, the interdisciplinary student laboratory "RoboScope" is being built to serve as an extracurricular learning venue. The aim is to interest students in technology through active experimentation in the scientific robotics discipline to motivate them to study subjects affiliated to science, mathematics, computer sciences and engineering. The article describes the didactic design of the student lab, which is modeled on the dual cycle of work-integrated learning according to Stefan Brall (2007). This cyclic learning process can be realized particularly in work- and activity-integrated contexts. The focus of the didactic concept lies on the implementation of experience-based, active experimental and consciously reflective learning. Concrete application scenarios from the area of robotics serve to show various interrelations of effects and allow insight into different scientific disciplines. Practical (experimental) and theoretical phases are passed alternately in iterative learning loops. With the help of successive modules (lane of demonstration, phases of experimentation, microteaching units, contest arena), special areas of activity are created for students where various scenarios can be explored interactively. These scenarios are linked to theoretical content in subsequent reflection phases. The project character of the student laboratory fosters not only subject-related skills but also meta-disciplinary competences like team skills and openness to criticism as well as project management. The interaction with such a diversity of scientific disciplines also helps the students with their future professional or educational orientation. The supervisors (undergraduates of technical and scientific subjects) coach and advise the attending students as experts and serve as role models for a transition from school to university.

Key words: Robotics, Technology Education

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1 RoboScope – An Innovative Student Laboratory

The student laboratory RoboScope of the ZLW/IMA (Center for Learning and Knowledge Management/ Institute of Information Management in Mechanical Engineering) of the RWTH Aachen University raises awareness of robotics and technology and gets students enthusiastic through active experimentation in the scientific discipline of robotics. The term "Scope" stands for development and operation possibilities but also for leeway for actions and ideas so that the students can determine by themselves which strategy they will use in order to solve the assigned task. The laboratory concept pursues a highly crosslinked teaching and research approach, which connects not only all disciplines from science and engineering with each other but also involves issues about medical engineering and social sciences as well as ethical questions. Topic-specific scenarios are developed under these premises. Further, particular attention is paid to make female participants aware of their talents and potentials concerning sciences and technology. Therefore, additional (gender-appropriate) topics from the area of man-machine interaction, biotechnology and medicine as well as moral and ethical issues are integrated. The main target groups of the robotics lab are high school students aged 10 to 18. Additionally, special courses are offered to mid-level secondary schools, special need schools as well as to alternative forms of schooling. Within the student laboratory the main focus of the tasks for all target groups is the autonomous experimentation in small teams and the demonstration of practical relevance. The lack of skilled employees in German enterprises will worsen presumably during the next few years due to the problems of demographic change. It is therefore essential to confront high-school students with technology-oriented topics at an early age to reduce their inhibition towards technology and to point out their potential. Thus, potential future employees are introduced to scientific and engineering issues in a playful and action-oriented manner. Subject-related qualification includes not only content specific to robotics but also aspects of engineering, sciences and social science. Consequently, the students are able to acquire a fundamental understanding of mathematics, science, computer sciences and engineering in the context of robotics. Additionally, meta-disciplinary skills such as team and presentation competences, critical faculties, time management and project management competences are trained. These abilities are increasing demanded in today's working environment. In order to meet the requirements of a holistic learning and teaching approach for students, a special didactic concept has been developed that integrates all the aforementioned aspects. The approach bases upon an experience-based learning concept, the dual cycle of work-integrated learning according to Brall. This model is introduced in chapter two. In the third chapter, the individual elements of the laboratory's didactic concept are presented and linked with Brall's model.

2 The Dual Cycle of Work-Integrated Learning

The model of the dual cycle of work-integrated learning according to Brall serves as the foundation for the didactic concept of the RoboScope student laboratory. Brall's approach, like the learning concepts dealing with robotics which are used in school, is based on the knowledge that experiences serve as an effective starting point for all kinds of learning processes [KRM74]. Essentially, the model consists of an experience-based learning cycle, which is passed through twice and in which phases of experience, reflection and development of new acting strategies alternate. Starting from the premise that every action is embedded in previous and current stories and discourses[1] [Sch03] the immediate experience constitutes the starting point of conscious learning. Models of experience-based learning, where novel behavior is derived from experience, describe how abstract concepts arise from observation and reflection of lived experiences. These concepts are used consciously in new situations. At the same time, new experiences are made. All experience-based learning models highlight reflection as a decisive factor of the learning process and simultaneously postulate this as the main element of adult learning. The critical observation and assessment of past experience permits the development of new operation models and perspectives which in turn form the foundation for new experiences and actions [LBH08]. The cyclic depiction of the learning process as an iterative loop of experience, reflection and development of new acting ways, stresses the necessity of a permanent evolution of knowledge and skills. This is the central assumption which Brall implements as the basis of his dual cycle of work-integrated learning. The cycle is different from other concepts insofar as it does not only describe adaptive learning processes consisting of individual experience but supplements this by active and planned action which "detaches itself from the experiences and creates future through learning" [Bra10]. On this account, the approach is particularly suitable as theoretical fundament for the conception of student-oriented robotic learning units.

Within this model, learning based on the reflection of experiences (experience-based learning) is connected to learning that generates actions (action-generating learning): In the first cycle the episodic experience (E) is transformed into an experience-based model of reality (EM) via reflection processes (R) (Fig. 1). Starting point for this experience-based learning process is a gap between knowledge and skill experienced either through experience at work or through experience in conscious actions. The second cycle depicts the conscious application of such a reality model in a learning process, which generates actions (H). The reflection on thus created new experiences (Fig. 1) develops relatively stable generalized models for actions (GM). These reality models directly correspond to concrete contexts [Bra08]. Since Brall as well as Schmidt [Sch03] assume that every action is necessarily embedded in previous stories and discourses. As mentioned before,

[1] According to Schmidt (2003), stories and discourses are symbolic 'mechanisms of order/organisation', created by every individual on its own as a result of reflexion, which constitute the embedding of actions and communications in a field of experience resp. in life practice [Sch03]

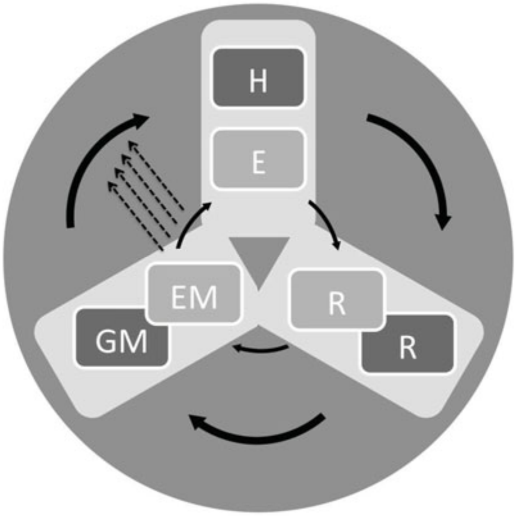

Fig. 1 The dual cycle of work-integrated learning (Brall et al. 2007)

those stories and discourses are integrated into the student laboratory RoboScope in the form of different scenarios. Intended and sustainable further development (i.e. permanent learning) within this model is only then possible if learning does not solely take place reactively based on previous experience, but when further cycles of acting and improving are passed through consciously. Especially experience-based learning thus has to be transformed into conscious learning processes. Besides actively observing and reflecting former experiences and deriving future action models this learning type also has to allow to look forward and creatively design a new leeway of action. The intentionality of the learning process thus is a decisive factor for future-oriented learning. Sustainability of an intended change can only be guaranteed if a conscious analysis and application is carried out in a test-action, which at the same time assesses and validates the achieved results. The attention of an individual consequently has to be focused on a certain learning subject for a certain amount of time in order to achieve improvement [Bra10]. By definition, the model deals with experience-based learning processes within a traditional work environment. In order to allow for the didactic realization of this model for the student laboratory, some additions are necessary which are described in the following chapter. In advance, it is important to state that learning processes within the student laboratory are not work-integrated processes, but rather practical, playful and self-determined activities. Additionally, the notion of “Stories and Discourses” has been supplanted by “Scenarios” for the didactic concept of the student laboratory. Those create the framework to communicate content related to the subject robotics. The focus of the student laboratory lies on the implementation of rescue scenarios and particularly the aspect of cooperative robotics[2]. The model core however comprises experience, action and reflection processes. The realization of these processes within the student laboratory is achieved through the implementation of different didactic elements. These are introduced and connected with the model of the dual cycle of work-integrated learning in the following section.

3 The Didactic Concept of the Student Laboratory

The thematic focus of the courses lies on the construction of various robot models with LEGO Mindstorms construction kits[3] (Fig. 2) and to program them. By using the graphical programming interface NXT-G (Fig. 3), which is appropriate for non-professionals, students' reservations towards programming interfaces are reduced. After a short introduction to the interface students learn through trial-and-error processes to program their robots to e.g. explore labyrinths, search for virtual victims in a simulated rescue mission or to dance a self-developed choreography.

The didactic approach of the laboratory focuses on creating practical, self-dependent scopes of action where students can try out the practical handling of learning subjects in various topical environments and have the opportunity to successively reflect problems under professional guidance. Combined with the analysis and evaluation of previous experience as well as with the resulting new knowledge, practicable solutions are then realized. The field of robotics is especially suited for this purpose as it permits vivid, practice-oriented learning and experimenting [XG08]. With the focus lying on robotics allows students a playful access to complex technological issues as the robots are mainly designed, built and programmed by LEGO Mindstorms. This pursues a creative learning approach that combines playing and learning. Such a learning culture is sensible especially for younger students since it allows for test-actions realized through trial-and-error strategies in order to gradually come closer to a solution [unt05]. It motivates and activates, takes away inhibitions and the fear of being asked too much while at the same time avoiding underchallenge and boredom through age-appropriate and challenging tasks which allow students to work towards success in a self-dependent way. Playful learning contains social experiences, self-reliant actions and the generation of action routines through intensified dealing with things learned earlier in both practice and theory [unt05]. Besides the dual cycle of work-integrated learn-

[2] Uny Cao, Fukunaga and Kahng (1997) define Cooperative Robotic Systems as a coalition of robots in order to solve a problem in a more effective way or to save time when solving a problem. Such a cooperation of robots is characterised by teamwork and combined behaviour that is directed to common interests and targets and which is usually based on communication. [UCFK97]

[3] Concerning the positive effects of the employment of LEGO Mindstorms robots in introductory programming and robotics courses: c.f. Williams, A.B., "The qualitative impact of using LEGO Mindstorms robots to teach computer engineering", IEEE Transactions on Education, Vol. 46, No. 1, p. 206, February 2003/ Gage, A.; Murphy, R., "Principles and experiences using LEGOs to teach behavioral robotics", proceedings of the 33^{rd} ASEE/IEEE Frontiers in Education Conference, Session F4E, Boulder, CO, November 2003.

Fig. 2 Example of a LEGO Mindstorms robot

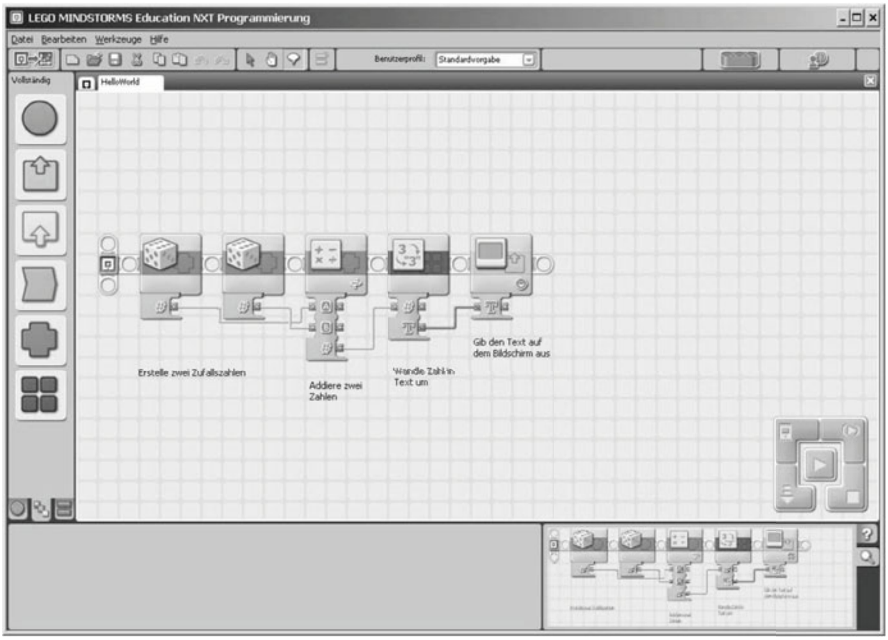

Fig. 3 The surface of LEGO Mindstorms Education NXT programming

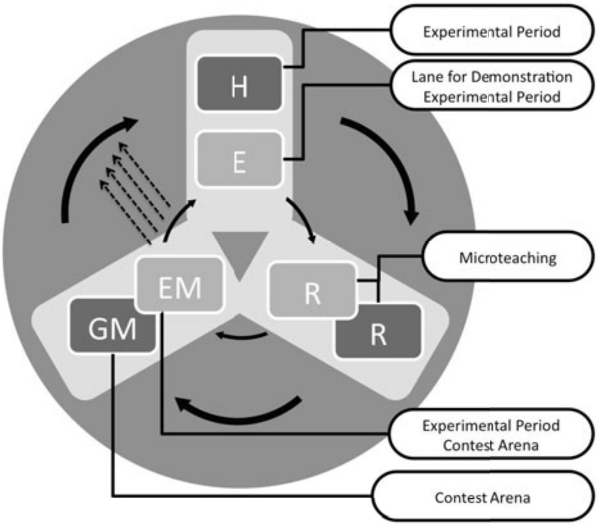

Fig. 4 The dual cycle of work-integrated learning in the example of the student laboratory

ing according to Brall, the didactic concept of the laboratory orients itself by the principles of student activation and action orientation [Gud08]. Students here do not act as passive recipients of abstract knowledge; they rather actively co-create the experience and learning processes. By means of the immediate practice relation of the laboratory work, the current working and living environments are integrated into the course schedules. With reference to Brall's model, the students gain (first) experiences with the discipline of robotics within the first learning cycle and then reflect these impressions under professional guidance. The second cycle however focuses on the implementation of gained experiences in specific actions in order to subsequently develop generalized models for action. Both cycles comprise different didactic elements which were developed especially for the application in a student robotics laboratory. Those elements include a lane of demonstration, phases of experimentation, microteaching units and a contest arena. In the following section, the individual elements are described and linked to the model of the dual cycle of work-integrated learning (Fig. 4).

3.1 Lane of Demonstration: Initiation, Confrontation, Motivation

The lane of demonstration offers a multimedia-supported presentation of interactive robot exhibits, e.g. land-moving or airborne robots, rescue robots, humanoid and insectoid robots, dancing robots, soccer robots or robo-pets, which are available for observation and for first experiments. This introductory module permits easy access to the topic of robotics and induces fascination for technological issues while at the same time it reduces inhibitions and builds up motivation. Hence, the access to the world of robotics is not primarily based on technological but most of all on emotional factors. It is crucial for the initiation of learning processes that visiting the lane of demonstration creates enthusiasm towards the subject to be learned [unt05]. Additionally it ties in previous experience and knowledge of students that already had contact with robotics due to their own interest or through confrontation via media. In the lane of demonstration, students have the opportunity to access the topic not only under cognitive but also under affective and psychomotoric respects: technical aspects are made available for non-professionals and can be accessed in an action-oriented way through first possibilities of experimentation. The initiation with the lane of demonstration allows students a practice-related connection to the topic and creates an orientation framework for the successive modules [unt05]. In the style of Brall's dual cycle of work-integrated learning, the lane of demonstration constitutes the first experience (E) with a learning subject. The successive module, the phase of experimentation, delves into further experiences building on these initial ones through self-dependent development. Additionally, the lane of demonstration has an impact on the qualification of meta-disciplinary skills, as it trains skills like perceptiveness, proactiveness and creative experimenting.

3.2 Phase of Experimentation: Action-Orientation, Student Activation and Own Experience

The phases of experimentation are characterized by active, cooperative and self-dependent executing of scenarios specially devised for students. The main task for the students is to construct, build and program topic-specific robots. After constructing the robots, corresponding scenarios are simulated in miniature operational areas. By means of active trying, testing and experimenting, students self-dependently develop solutions for specific tasks that are subsequently evaluated and optimized if necessary. In order to cover different forms of work that students have to face in future working life, the phases of experimentation feature single, team and project tasks. The differentiated, robot-specific experiences made by students during the phases of experimentation correspond to such experiences (E) as are described both in the first and the second cycle of the model. The experiences from a first phase of experimentation primarily constitute a learning process based on reflection of experience (R) and the implementation of the resulting experience-based model (EM) for action. Based on this first learning process and first theoretical learning units to induce reflection, new experience is made in subsequent experimentation phases through application of the generated abstract model for action.

These new experiences are schematized in the second cycle of Brall's model where the following observation and evaluation of experience made results in action-generating learning that produces generalized models (GM) for action. Both the experience-based models for action depicted in the first cycle of Brall's model

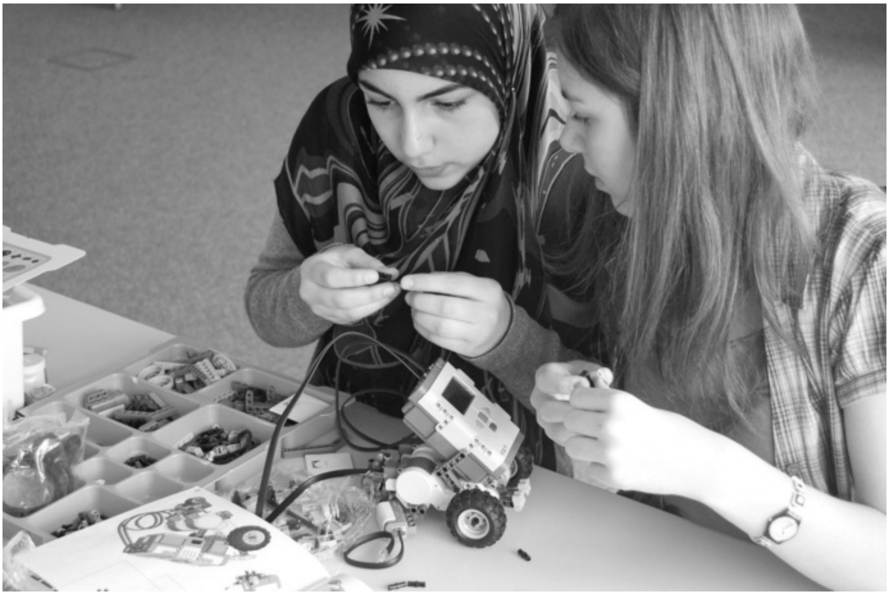

Fig. 5 The Phase of Experimentation in the student laboratory

and the generalized models for action of the second cycle can be applied, tested and reflected during the phases of experimentation. Hence a permanent learning cycle is created that is aimed at continuously improving previous cognitive and/or psychomotoric conditions. The phases of experimentation focus on principles of activation and action-orientation. The action-oriented approach of the student laboratory allows for holistic learning and teaching where working with both brain and hands supplement each other and are balanced in proportion [Mey06]. The products (robots) created during this process are a decisive part of student- and action-oriented learning: They permit a high level of identification with the work and the resulting outcome. This is why learning and action processes are closely connected at the student laboratory [unt05]. This corresponds to the demands of work environments that students will encounter during their future professional careers. Permanent work-integrated learning processes play a decisive role for innovative ability and sustainability of an enterprise.

3.3 Microteaching: Conveying Subject-Related Knowledge and Creating Space for Reflection

For the purpose of an experience-based learning cycle, practical-experimental phases alternate with theoretical learning units. The theoretical contents are incorporated into robotics courses by means of microteaching modules. A microteach-

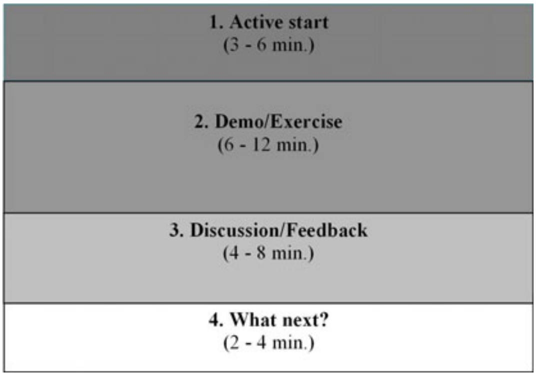

Fig. 6 The structure of a microteaching unit

ing unit takes 30 minutes at most. During the student laboratory, the units are held in a classroom with multimedia equipment. Microteaching is a time-efficient and learning effective strategy to convey information and theoretical knowledge within a short amount of time. The term "Teaching" basically describes all learning processes that consist of knowledge conveyed through input. This time-saving method is characterized by a rapid exchange of knowledge and making use of the expertise of one or more persons [Leu10]. Every microteaching unit is structured into an active start, a demonstration resp. exercise, a discussion or feedback and a preview on what will happen in the following microteaching units (Fig. 6) [DVB08]. Microteaching currently is integrated into work processes by many European enterprises and aims to optimize the transfer of sustainable knowledge. The key to a successful implementation of microteaching lies in the immediate application of the acquired knowledge into (professional) practice [DV07].

Within the student laboratory, the interactive microteaching units are used to convey theoretical background to previously practical experience gained and to connect them to a complex technological background. The according materials are designed to be age-appropriate. The integration of the microteaching concept makes sure that the laboratory does not lose its experimental character through excathedra teaching of theoretical inputs. Microteaching is moderated by trainers that provide learning materials and direct, but not decree, the learning processes. This method makes sense especially when applied in small groups and connects experience and contexts of action directly with theoretical knowledge. Additionally, participants are activated through the use of a multitude of teaching methods and materials as well as through their direct involvement in the layout of the learning unit. [mic] Related to Brall's model, microteaching units correspond to phases of reflection (R) and evaluation of experiences that later serve to derive experience-based models (EM) for action. At this point, it is crucial for the learning process that microteaching units do not only convey theoretical knowledge to previous experiences but also serve as a conscious, professionally guided reflection of the individual experiences from the work phases that encompass aspects like teamwork experience, motivation, time management and ethical and moral issues of robotics. The intentionality of reflection and the temporal closeness of cause-and-effect relationships experienced by students through this combination of experimentation and theoretical phases are significant for the generation of models for action. [Bra10] Only repeated reflection (R) of experience (E) permits action-generating learning and thus the development of stable generalized models (GM) for action that constitute the foundation for further experience and reflection not only in further laboratory work but also for a sustained future handling of similar thematic fields and of similar contexts. This cyclic process is the prerequisite for permanent sustainable learning.

3.4 The Contest Arena: Testing Models for Action and Training for Competitive Situations

The contest arena offers students an opportunity to measure their independently built robots with those of other teams. It is a boost for interest and enthusiasm if students know that their product will compete with the ones of other laboratory participants. The competitive situation creates a higher motivation than traditional performance queries known to students from school. It is an unaccustomed but welcomed challenge to students if it is all about "producing such results that beyond the improvement of one's own knowledge are newsworthy to others" from the start [Gud08]. Additionally, the presentation of the robots in itself is an important part of the learning process. Explaining one's own work processes and exhibiting one's own robot once again renders laboratory work a communicative process and yet again adds to the laboratory work's character as being a communicative process [Gud08]. Furthermore the contest arena trains to cope with competitive situations. Students learn to handle resulting stress and pressure and to compare their own experience and capabilities with others. Moreover, competition boosts team spirit and incites creative thinking. The space for the contest arena consists of a large area to present the different robots, and an amphitheater with seats for spectators that underlines the arena character. The construction is flexible and mobile to facilitate its setup in other areas.

Observing the learning results of other groups initiates a reflection process that permits assessment and evaluation of the own and the others' work. Additionally, it allows the integration of the solutions of other groups and action patterns into one's own thinking. The contest arena serves to consciously direct the students' attention towards their own results as well as the achievements of other teams activate another reflection process of applied actions and action patterns (H). Thus, the contest arena does not only provide space for conscious testing of experience-based and generalized models for action developed by the students in various cycles of experience, reflection and evaluation. Furthermore it permits students to consciously modify

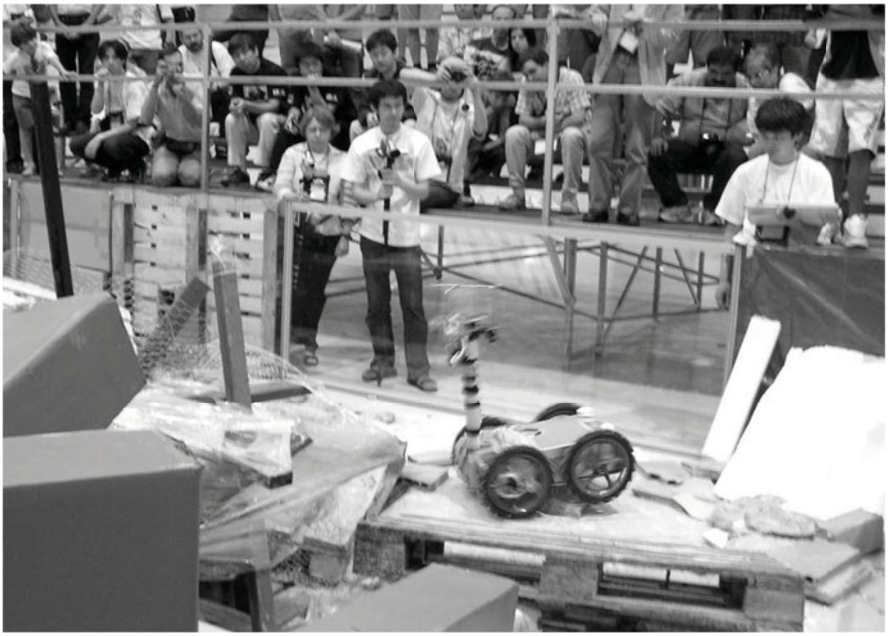

Fig. 7 A contest arena

implemented action patterns in order to initiate further learning cycles that are also characterized by intentionality and aim at continuous development and improvement. Experience (E) gained in phases of experimentation and competition thus are classified and assessed through verification by others' experiences and subsequent joint reflection. The phase of competition thus constitutes a central item within the didactic model of the student laboratory. This is all the more the case as the students' experiences are even more practice-related since the competition is a real situation. The experiences gained here are therefore even more in direct connection to the students' future living and work environment.

4 Development of Meta-Disciplinary Skills

TAs already mentioned, the student laboratory does not only focus on developing subject-related technical skills and scientific issues. The connection of this area of skills with meta-disciplinary competences like critical-exploratory thinking, cooperation and team skills as well as project and time management offers opportunities to make students aware of the importance of these soft skills. It is necessary to educate them in an interdisciplinary manner and to prepare them for the increasing requirements for graduates of scientific, mathematic and engineering studies regarding social and communicative competence. Key qualifications in the area of science and engineering increasingly encompass skills like reflective ability, communicative competence, the ability to concentrate, creativity and innovative ability as well as stamina and self-accountability. The activating, practice-related and conjoint character of the laboratory serves to train these skills in the sense of a comprehensive, holistic education [mob06]. The content diversity as well as the methodological diversity of the student laboratory aim to connect subject-related and meta-disciplinary qualifications: Visual-auditory observations in the lane of demonstration supplement activating, practice-oriented phases of experimentation and microteaching units that link practice with theoretical knowledge, encourage reflection and, in connection with the phases of experimentation, prepare for the competitive situation in the contest arena. By switching between practical and theoretical phases, the laboratory serves the different requirements of the different learner types. At the same time, students are being prepared for the demands of their future workplace since flexible application of interdisciplinary skills increasingly becomes a prerequisite. The student laboratory concertedly fosters professional orientation through intensive practice-relation: the practical phases serve to impart a realistic conception of work and research environments in the area of engineering. These profession-oriented elements are complemented by thematically linked microteaching units to convey a comprehensive picture of technology-oriented fields of work.

5 Space Concept

The Laboratory is based on a One-Room concept which facilitates explorative access to technological fields of topic and supports both informal, social learning and the style of work of the individual student. Therefore, a large laboratory hall has been subdivided into different areas, among them an experimentation area, a construction and testing area, a microteaching room with multimedia facilities and a contest arena (Fig. 8).

A robot-controlled material center, where students can order necessary materials to plan and build their robots, illustrates the practical application of robots in everyday professional surroundings and completes the innovative space concept. Traditional learning environments like front-oriented settings, sitting circles and table clusters are available as well as special learning environments that provide leeway for creative and self-dependent work. This helps to react flexibly to the varying demands of participating students. Learning media can be adapted to age and size of the laboratory participants same as the required furniture: multi-functional playing and experimenting tables, ergonomic chairs, research stations, mobile flip charts, whiteboards and high-class technical equipment support a varied learning and working atmosphere and additionally facilitate seamless integration into professional robotics research labs.

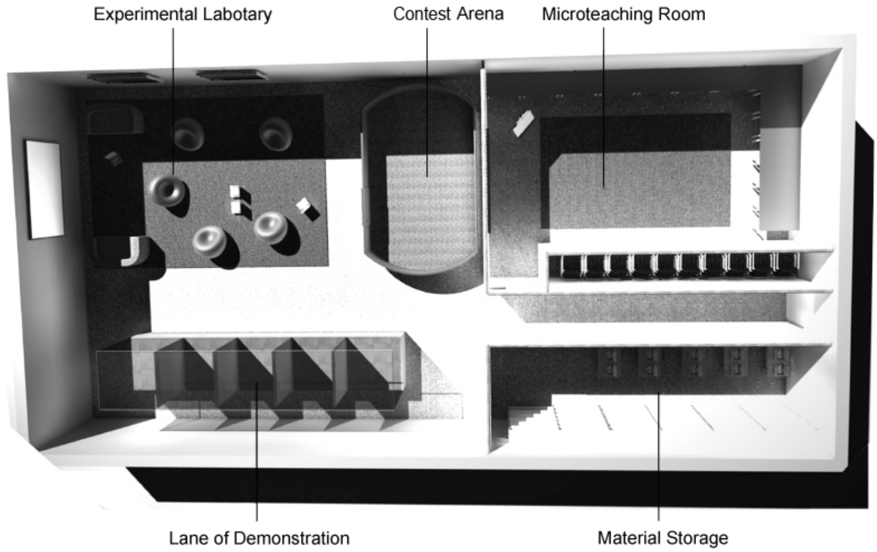

Fig. 8 Space concept of RoboScope

6 Summary and Outlook

The didactic concept of the student laboratory RoboScope is specially suited to achieve the subject-related technical and meta-disciplinary educational targets described. During the development of the conception of the didactic elements, current scientific insights (dual cycle of work-integrated learning according to Brall) concerning experience-based learning concepts were continuously integrated into the planning and development work. Within the didactic concept, experiencing processes are the basis for all implicit learning processes which primarily take place playfully, practically and experimentally. The iterative integration of theoretical inputs into practice-oriented phases of experimentation on the one hand and the conscious reflection of experience and actions on the other hand fosters a permanent learning process geared towards continuous improvement. Enterprises and organizations from all professional fields, especially those from technical, engineering and scientific areas, are dependent on lasting, sustained learning in order to remain innovative and competitive. Beside the sustainability and future viability of experience-based learning processes, motivational and interest-creating effects of such a didactic approach constitute a crucial additional value. For that reason, the employment of action-oriented and activating learning concepts is increasingly called for and implemented, especially within schooling contexts [Mey06]. Experience-oriented and activating principles help to convey complex subject matters and particularly aim to train meta-disciplinary skills by naturally integrating aspects such as team work, co-operation, competition, communication and creativity into the learning process. Facing an increasing lack of skilled personnel in German enterprises, students should be made aware for technology-oriented and scientific topics at a very early age.

This sensitizing takes place at the RoboScope student laboratory mainly through affective and psychomotoric factors that facilitate a cognitive theoretical approach and arouse fascination to the topic of robotics. Principles of activation as well as experience and action orientation assist this emotional dealing with a technological subject of education. Learning outside traditional schooling contexts, without grading, fixed curricula and tests makes students assume their learning success as their own self-determined process leading to a more intense identification with their results. Technological and scientific topics are dealt with by starting out from the students' own realities of life and by means of concrete experience situations permitting students to create continuous references to reality.

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Robotics Education Labs – EDULAB

Alan Hansen, Frank Hees, Sabina Jeschke, Olivier Pfeiffer

Abstract As one of the largest technology-orientated universities in Germany, RWTH Aachen University possesses a broad MINT (MINT – German acronym for Mathematics, Engineering, Natural Sciences and Technology) profile encompassing almost every area of mathematics, computer sciences, natural sciences and technology disciplines. One of the main goals of the MINT agenda of RWTH Aachen University is to enthuse high school students for MINT subjects through a targeted recruitment strategy during the transitional phase from school to university. Focusing on the field of robotics, EDULAB supports this strategy by introducing high school students to the MINT subjects and getting different facets of the technological disciplines across to them. To this end, rescue-scenarios are especially suited as topics from engineering, medicine, mechanics, biology, information-technology and mathematics are integrated per construction. Robotics is a holistic field of research, encompassing and addressing all MINT subjects. Additionally, socio-scientific perspectives of the MINT subjects are integrated into the EDULAB master plan.

Key words: Robotics, Rescue Scenario, Technology Education

1 Introduction

The main goal of all existing MINT programs at RWTH Aachen University is to foster high school students' interest and the enthusiasm for MINT topics by different activities and to support them in choosing their major and their career choices through intensive activities with MINT subjects. Here, robotics is employed as a per-

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Fig. 1 The next MINT generation during a one-day introductory robotics course, working with LEGO Mindstorms NXT

fectly suited central discipline of the high school students' laboratory EDULAB because of the multitude of technologically oriented disciplines (e.g. information technology, mathematics, physics) that can be holistically represented and thus imparted in a well-directed way.

The project character of the high school students' laboratory and the possibility of actively participating in different experimental activities help to enlarge the MINT-related skills and competencies of the participants particularly. Special offers are addressed at high school students with a migration background. By varying degrees of difficulty and complexity, the high school students' laboratory guarantees an age-based and qualified insight into science and research. Specific activities for boys and girls also broach the subject of gender diversity [Him06]. Social, communicative and media competencies are promoted in multimedia learning environments and interdisciplinary problems. Socalled "insiders" (student assistants) are in charge of giving high school students the the chance to become acquainted with RWTH Aachen and particularly the MINT programs.

In the following chapter we describe and highlight differences from similar projects, particularly those offered at RWTH. In the third chapter we outline each success factor of the EDULAB program: experimental character, anchorage in the region, variety of target groups and programs, advancement of girls, partners, staff concept, and sustainability. Finally we conclude with an outlook on our future work.

2 Related and Prior Work

ZLW/IMA has a lot of experience and knowledge regarding recruitment and promotion of the next MINT generation: In the context of the "tasteMINT" [tas] project an innovative potential assessment-procedure is being developed. On the one hand this supports female high school graduates in discovering their interests for the MINT subjects during their transition from school to university; on the other hand strong points can be put to the test and developed further. An earlier project by ZLW/IMA within the range of MINT studies was "DO-Ing" [doI]. This project was funded by the German Federal Ministry for Education and Research (BMBF) to catch the attention of girls and women for engineering programs at universities. The main goal of this project was to give all interested girls from the age of 10 to 16 an insight into different technical businesses and public institutions. Resting on the experience-based learning cycle [Kol74] extensive learning scenarios have been developed [Bra09, HBB07, BH01, BS84].

2.1 Differences and Extensions to Existing Projects

Existing efforts in Aachen and vicinity for boosting the next MINT generation are currently limited to the zdi-centere ANTalive in Düren/Aachen [aac] and the JuLab at the Jülich Forschungszentrum [jul]. As far as possible ANTalive and JuLab follow an inductive approach in creating interest for technical disciplines. Complementary, EDULAB utilizes robotics as center (deductive) and starting point to raise interest and acceptance for the MINT subjects. One of the main differences between EDULAB and these offers is its deductive didactic approach. Beyond the offers of ANTalive and JuLab, EDULAB offers one-day programs, summer-/winter-schools [Lämb], workshops for students as well as course programs for students providing them with a long term support of their MINT interests. To this end, in close interconnectedness with further activities at RWTH, forward-looking fields of research are established in the vicinity of "cooperative robots" and HRI. The EDULAB offer specifically also addresses students from regional primary and secondary schools. Here another separating aspect exists as the ANTalive concept focuses especially on high school students. Just because of the different didactic approaches a variety of cooperation possibilities with the already established zdi-centers in the region exists. This linkage could be established in the form of supplementing modules and experimentation possibilities for example. In this sense the EDULAB courses can be integrated as an extension of the technological perspective around the field of robotics into the zdi-centers ANTalive and JuLab. ANTalive already offers introductory robotics courses in cooperation with RWTH. In the context of the EDULAB approach these experiences can be systematically deepened. After establishing contact and discussing cooperation possibilities with the zdi-center ANTalive and JuLab corresponding LOIs have been signed.

3 Implementation

In the following we describe the pillars of the EDULAB project.

3.1 Experimental Character of EDULAB

In EDULAB the individual, experimental approach to technology takes center stage. Practical experiences in handling technology that students gain by conducting robotics experiments are the focus of the didactical concept. Fears of contact of the students with MINT-related topics are reduced by an active trial and testing approach in the students' laboratory. With different experiments and assignments from the robotics area, simple and complex objects and processes are examined and thus new realizations and insights are won. Solutions for specific problems (e.g. rescue scenario) are sketched, optimized, examined and tested by actively experimenting in the laboratory. For the completion and addition of the didactical concept learning units are integrated, which are imparted by the microteachings. The content of each learning unit refers to the thematic center of each respective laboratory experiment. Practical, experimental and theoretical stages alternate in repeating loops. If necessary, this iterative process can be extended in each process loop by more complex and more difficult tasks and experiments. This way the process can be transferred to situations of everyday life, e.g. experiments on the IKA-test-track, rescue scenarios in the "Floriansdorf" of professional firebrigade Aachen (center for safety education and recon).

3.2 Anchorage in the Region

On basis of recent research schemes from the project "Learning without Frontiers" to the realization of offers in the region, we aim at a close cooperation with the Office of Educational Affairs of the municipal region of Aachen. The purpose of the Office of Educational Affairs is orchestrating and concentrating academic and extracurricular activities in promotion of young people. The students' laboratory in cooperation with the Office for Educational Affairs contacts schools from the region and utilizes these strategically to recruit students. Moreover, one of the short term goals is to extend the laboratory in cooperation with the exploregio.net-association [exp] to be a part of the "Außerschulische Lernorte für Natur, Kultur und Technik"-Network. Together with members of the neighboring federal states the association supplements the conventional educational learning opportunities in the region. In co-operation with the mentioned partners MINT-topics are embedded into different realms of experience for the students. Moreover the different topics covered by exporegio.net are especially suited for addressing and recruiting girls as MINT offspring. Depending on their complexity the robots designed in the stu-

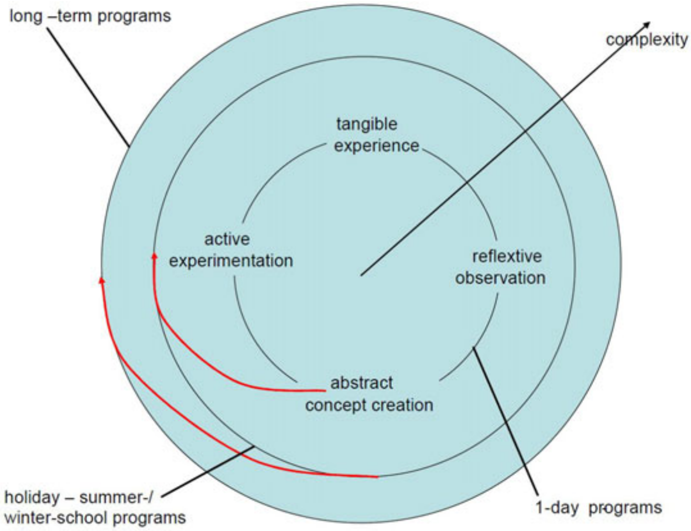

Fig. 2 Graphic illustration of the EDULAB concept

dent's laboratory can be integrated in diverse application scenarios, e.g. deployment of rescue robots in underground mining facilities. The combined traffic-simulator (rail, road and air) of the ZLW/IMA is already integrated into exploregio.net's offers.

3.3 Diverse Target Groups

The co-operation of the EDULAB with the Office of Educational Affairs of the municipal region of Aachen, as described above, offers a big networking potential with schools from Aachen and its surrounding areas. Beyond that a close contact of the EDULAB to schools of all different educational levels is guaranteed. Apart from cooperation with students of the upper levels of high schools and vocational colleges at least 30 % of the offers and/or the temporal capacities of the students' laboratory are reserved for students of the (lower) secondary school level of high schools, intermediate secondary schools, secondary general schools, special schools and other types of schools. The laboratory concept itself allows for a flexible adjustment teaching and learning contents for the different age and target groups. Hence, the student's laboratory is suitable not only for students in the upper levels, who are on the verge of choosing their professional career but also for younger children. The degree of difficulty and the complexity degree can be individually adapted by different task-settings and/or robot kits to the age of the respective pupils. The authors gained first experiences in teaching of MINT topics by means of robotics at the RobertaRegioCentres of Technische Universität Berlin and at the University of

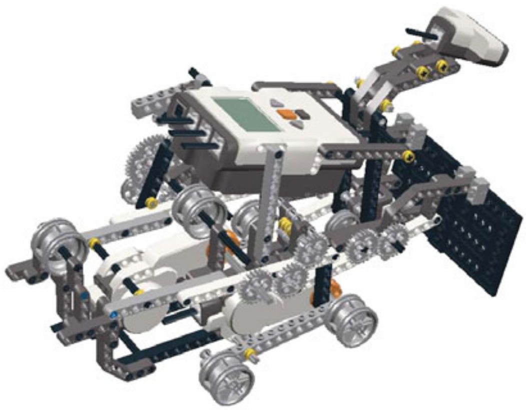

Fig. 3 "Snowwhite": A snow plowing robot, designed, built, tested and presented during a course

Stuttgart. The courses taught there address students and especially girls from elementary schools and from junior high schools This broad offer gives every student the chance to experiment in the laboratory and discover so far unrevealed interests.

3.4 Advancement of Girls

From the multiplicity of technological research disciplines, robotics has a special fascination for (most) humans. It even puts those under its spell who are otherwise somewhat reserved towards technology. The student's laboratory EDULAB pursues a broad interdisciplinary approach that is demanded especially by girls and women. Because of its medical, biological and social aspects the rescue scenario is especially well suited to address female participants. A discussion of HRI allows for further examination of sociologic and psychological aspects, especially addressing female students. We integrate examples of robots from the above-mentioned and other areas, e.g. bio-robots, dancing-robots, into a showroom that particularly appeals to female participants.

Moreover, stressing social and communicative aspects during all project phases paves the way to technology for the students. By allocation and differentiation of different fields and associated roles during the experimentation phases students experience the necessity of interdisciplinary cooperation. At a later stage in this context we will try to confer coordination roles during the experimentation phases to girls, demonstrating that females are able to take lead roles in MINT subjects thus raising the awareness for the need of social competencies within the scope of technical project management. In order to attract students' attention for EDULAB we use different public relations instruments. Specific networking potential has been identified allowing for integration into existing curricula. Besides posters and flyers that were designed to specially address girls and are distributed in schools and youth centers we undertake joint recruiting activities in cooperation with the central student advisory service of RWTH Aachen University. In the context of the "Girls Future Day" and appearances of the RWTH-Science-Truck at information and advisory events, the student's laboratory is advertised.

3.5 Variety of Offered Programs

The courses offered by the EDULAB reach from one-day trial courses up to summer and winter schools and work-shops for students as well as course programs, in which rescue scenarios are treated predominantly. In the medium term however, further scenarios of cooperative robotics and with rising complexity degree intelligent robots are to be developed and built. The groups present their solutions developed in the different courses at the end of each program in groups in a competition and for students from the workshops a participation in various robotics competitions is planned. Clearly, in order to realize this extensive program spectrum, robot platforms and kits must correspond to the complexity degrees of the respective tasks. In the context of in one-day trial courses particularly LEGO Mindstorms [leg] robots and programmable FischerTechnik [fis], whereas with summer and winter schools and in workshops for students and course programs e.g. the more complex Asuro [are] robots (Fig. 4) and other, on the hardware end more challenging kits can be used reasonably. Example projects from these programs are the development of microcopters [mik] and autonomous aircraft. In order to increase the experimental character, have a realistic approach in the competition, and broaden the offer, cooperations with the Floriansdorf Aachen [flo], the processional firebrigade Aachen (rescue scenarios) and the IKA of the RWTH Aachen (testing of autonomous vehicles) are planned. Especially for the one-day trial courses a test/match arena is set up in the premises of the EDULAB, in which a typical rescue scenario is realized in a miniaturized form.

3.6 Faculty/Staff-Development Measures

In the context of the EDULAB an intensive staff exchange with schools from the region is taking place. Contact points and common grounds of the respective subjects are analyzed in order to allow for an integration of the object of robotics research into class. Technical teachers as well as teaching staff from the humanities are at the center of this process. This holistic approach presents the faculty with plenty of reference points for integration into already existing and planned curricula. Regarding this point a close cooperation with the "LFG Didaktik der schulischen und beruflichen Bildung im technischen Bereich" (Teaching and Research Subject Didactics

Fig. 4 "Asuro" a tiny mobile robot developed by the German Aero-Space Center (DLR)

in Technical Academic and Vocational Education [ins]) is of great importance. Students who are enrolled to be a high school teacher can attend an extracurricular practical training in the EDULAB as part of the "Fascination Technology" study module. Moreover, robotics is a seminar topic, in which these students can develop integrative teaching concepts for technological subjects. The EDULAB concept provides an intensive exchange as to the elaboration of specific measures for staff/faculty development and the integration into academic curricula. A discussion about some applications of robotics in school as initiation before visiting the students' laboratory as well as an adequate follow-up of results and impressions offer central starting points in this context.

3.7 Partners

3.7.1 Cooperation with other Students' Laboratories

In the EDULAB framework robotics serves as cloud point from which different field-specific and societal aspects are addressed deductively. In this context the diverse interdependencies are pointed out with self-experienced use cases. The laboratory focuses on the engineering sciences so that manifold thematic points of contact exist. EDULAB also profits from the targeted recruitment activities by the go4IT initiative accomplished by the SLI! that captivates approximately 500 girls for computer science and technology related fields per year. Cooperation with the zdi-center ANTalive and the JuLab guarantees an adequate networking with other MINT promoting students' laboratories. As a partner of these programs EDULAB will provide additional modules for the offers of the JuLab and zdi-center ANTalive.

3.7.2 Other Partner Institutions

- LPE LEGO Mindstorm Powerseller: The company LPE technical media GmbH is involved in the students' laboratory by their conception of the assigned learning materials (LEGO Mindstorms).
- Microsoft: Microsoft's Aachen office supplies the "Microsoft Robotics Developer Studio" (MRDS) that is used for simulating and controlling robots e.g. with LEGO Mindstorms and FischerTechnik kits
- Aachen Registered Robot Society: The Aachen Registered Robot Society places different robots (e.g. football robots) at the students' laboratory disposal, which are exhibited in the show room to calling for a wow-effect from students.
- Floriansdorf of the Aachen professional firebrigade: The Floriansdorf Aachen is a center for safety and recon education and contributes with its various offers, e.g. "house of dangers", fire station, hospital to secure the reality relationship. The participants of the students' laboratory can test and verify the functionality of their selfmade rescue robots in a real life situation on the outdoor premises.
- Vehicle test track at the Institute for Vehicles (IKA) at RWTH: The cooperation with the IKA adds an additional dimension to the program: on the approximately 600 m long test track that is predominantly used for the development of guidance, information and communication systems and for tire and roadway noise measurements, the participants of the students' laboratory can test their selfmade robots.
- Aachen Municipal Region exploregio.net: The partnership with the Office of Educational Affairs of the municipal region of Aachen and the exploregio.net association contact to schools in the region is established. EDULAB complements the regional initiative for the advancement of out-of-school places of learning and has its share in strongly inspiring young people for technology.

3.8 Staff Concept

The interdisciplinary organized ZLW/IMA takes care of the organization and development of the necessary infrastructural measures with its own staff resources. Thus, the most diverse expertise is already at hand. One full-time staff member is responsible for carrying out all laboratory business from organization, coordination, maintenance, procurement to training measures. The train-the-trainer approach [BH01, BS84], that has been employed at ZLW/IMA for 30 years in the context of diverse activities, e.g. FIT for University, Group of Tutors, project assignments in computer science for mechanical engineers, laboratory on development of

Table 1 Implementation schedule

Stage	Implementation-step	
1. Initial period and participant recruitment	• Assembly of technical and didactical infrastructure (incl. development of learning scenarios) • Staff preparation and/or training of staff • Procurement and preparation of the teaching material • Conceptual design of the learning units for the rescue scenarios (one-day-courses) • Website design and initial marketing activities	• Publicity-oriented measures and marketing campaigns announcing the students' laboratory • Continuous staff preparation and/or training • Organizing and maintaining contact to schools in the region
2. Laboratory launch	• Implementation of beginners courses with focus on elementary and secondary school children starting 7/2010 • Preliminary conception of summer and winter schools and courses of several days duration, workshops for students and programs highlighting further applications of cooperative robotics	
3. Extension and test	• Development of complex application scenarios by integration of out-of-school learning places with different thematic emphasis • Further development of robotics-specific teaching material for application scenarios with a higher degree of complexity and test with pilot groups (diversity concept)	
4. Regular operation	• Implementation and integration of the complex application scenarios in the laboratory • First participants' competitions, e.g. RoboRescue and RoboCup	

communication and organization, is at the core of the staff concept. An expert takes over initial and continuing training of educators and student assistants and is always available as permanent advisor while other activities are being carried out. To this end five student assistants with MINT and didactic background have been appointed to train the trainers.

3.9 Sustainability

The beginners courses in which predominantly LEGO Mindstorms are used to design, build and program robots, are free of charge for participants thanks to the funding by the State Ministry for Innovation, Science, Research and Technology (MIWFT) of North Rhine-Westphalia. For the implementation of one-day-courses for advanced participants and/or more complex activities, e.g. summer and winter schools and course programs a participation fee has to be levied to safeguard the sustainability of the institution. The participation fee of €40 (approx. $60) per person includes the teaching materials and the year-round courses are offered for a participation fee of €120 (approx. $175) per person. The fees raised for summer and winter schools cover travel expenses, accommodation, and teaching materials.

4 Future Work

TAs part of the future concept of RWTH Aachen University, a program [Nor] has been developed, targeted at "setting people in motion". One component of this concept is the MINT cooperation program, by which pupils shall be inspired for technical-scientific disciplines (e.g.: taste-MINT, girls' day, pupils' university, TANDEMkids [Läma]). The ZLW/IMA is actively involved in these measures, amongst others the projects tasteMINT [tas] and DO-Ing [doI] are coordinated by ZWL/IMA. We are currently working on setting up a financial concept to facilitate the participation of children from financially less privileged families in all activities based on a sponsorship model.

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Bachelor+ A Year Abroad with NIDI-INTERNATIONAL

Sabina Jeschke, Nicole Natho, Olivier Pfeiffer, Christian Schröder, Erhard Zorn

Abstract Goal of the NIDI-INTERNATIONAL project is to redesign and implement an existing program in order to integrate one year of study abroad for students. In this article we outline the design, implementation the BSc course of "Natural Sciences in the Information Society" that started in the winter term of 2007/08. We also describe a prototypic student project in the framework of the LiLa project that has to be implemented in the second semester abroad.

Key words: Bologna, Study Abroad Programme, New Media in Education, Remote Experiments, Virtual Laboratories

1 Background and Motivation

The BSc-program "NATURAL SCIENCES IN THE INFORMATION SOCIETY" (NIDI) [JNP+07] at Technische Universität Berlin (TUB) addresses students who are seeking a comprehensive natural scientific education. Their field of activity consists amongst other things of the areas of management of natural-scientific or engineering projects in an international context.

Goal of the NIDI-INTERNATIONAL project is to integrate in the curriculum a one year stay abroad for as many students as possible. In the medium term the year abroad shall be integrated for all students in the regular period of study of eight semesters to augment their professional qualification.

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In the context of the DAAD-programme "DIES"[1] the School of Mathematics and Natural Sciences at TUB is currently already cooperating with Escuela Politénica Nacional (EPN) in Quito, Ecuador on a for your project "Strategic Faculty Management". Within the framework of the "Erasmus Mundus External Cooperation Window Lot 3/4" TUB has been cooperating with Princess Sumaya University for Technology (PSUT) in Amman, Jordan since four years.

The BSc programme "Natural Sciences in the Information Society" was developed in the context of the study reform project GALILEA and introduced in the winter term 2007/8. Goal of the GALILEA project is to raise the attractiveness of natural-scientific and engineering programs. To this end exemplary programs are developed that shall particularly attract women. In the winter semester 2009/10 the program had 72 students of which 35 were women.

Currently the BSc of "Natural Sciences in the Information Society" is a six semester program. Course achievements can also be made abroad. However, the involved structural challenges, e.g. accreditation negotiations make such a venture very complicated for the individual student.

Thus, the goal of the NIDI-INTERNATIONAL project during the first two years is to create a framework that makes it feasible for students to combine an extended stay abroad with the acquisition of additional qualifications. The students delve into their partner universities and acquire international competencies and cultural insights during their vocational preparation. All study achievements from abroad are accredited via learning agreements. At the same time the "NATURAL SCIENCES IN THE INFORMATION SOCIETY" program is revised to a eight semester program integrating one year of studies abroad.

2 Goal

The BSc program "Natural Sciences in the Information Society" addresses students that are interested in natural sciences and engineering, yet would decide against the traditional programs. Particularly women shall be inspired by this program for natural sciences and engineering; economy as well as society have a growing demand for multi-disciplinary qualified graduates that have a comprehensive scientific knowledge. This multi-disciplinary is application- and research-oriented. Methods and basics from computer science, mathematics and natural sciences are put across.

The combination of these subjects is completed by choices from other natural scientific/technical and non-technical disciplines and forms the basis for the development of a comprehensive natural scientific methodological expertise. During their undergraduate studies the students acquire natural scientific basic knowledge and acquaint themselves with general and subject-specific problem solving methods in natural sciences. These competencies facilitate the transition to professional life and prepare as well for the commencement of graduate studies.

[1] Dialogue on Innovative Higher Education Strategies

Programs at TUB have already converted to the Bachelor/Master system and numerous engineering and natural scientific programs are offered.

Currently the following six Bachelor programmes are offered at the School II "Mathematics and Natural Sciences" are offered: Mathematics, Techno-Mathematics, Mathematical Economics, Physics, Chemistry as well as NATURAL SCIENCES IN THE INFORMATION SOCIETY. This offer is completed by master programmes in Mathematics, Techno-Mathematics, Mathematical Economics, Physics, Scientific Computing, and Polymer Science. The master programmes Chemistry, Catalysis, Natural Sciences in the Information Society are currently under development.

Currently all BSc programs are tailored for 3 years of studies, while MSc programs last 4 years. The program "Natural sciences in the Information Society" completes the traditional programs with its layout and objective and emphasizes TUB's commitment for the implementation of the DFG[2] gender equality norm to recruit more women for technological disciplines.

By signing the university contracts for 2010–2013 with the Federal state Berlin TUB earned the possibility to develop new study models (cf. university contract 2010–2013 § 11 [fed, JNP+07]). In the context of this regulation TUB wants to develop several eight-semester bachelor programmes with a pilot character and a different structural organisation. In the context of the BACHELOR PLUS programme we want to develop such a structural model.

3 Structure of International Program

Approximately one third of the required courses have strong international features (cf. Fig. 1): In the field of the natural sciences there is English as lingua franca. The students are introduced to everyday research life by offering a part of these modules of the programme in English. In the modules "Scientific Information Management" and "New Media in Education and Research" national and international standards from scientific practice are introduced, discussed and applied, if possible (e.g. use of international literature data bases, mutual Peer Review of the studying to own work, lectures before external specialized public).

Likewise, a component of these modules is the acquisition of comprehensive information literacy. In the module "Computer-oriented Mathematics" the students acquire the ability to write own complex programs in a modern programming language (Java). The international impact amongst the (required) elective modules strongly depends on the students' choices and mentors provide advice to their mentees concerning their stay abroad.

A selection and matching procedure will identify the suitable candidates amongst the interested students, who will be able to participate in the PRIMUS[3] programme.

[2] Deutsche Forschungsgesellschaft – German Research Foundation

[3] PRIMUS: Programme for the Internationalisation of exeMplary Undergraduate Study programmes (Programm zur Internationalisierung modellhafter Undergraduate-Studiengänge)

	Required Courses									
Term / Location	Mathematics	Computer Science	Natural Sciences	Information Management	Required Electives	Electives	Vocational Preparation	Bachelor Thesis	CP per Term	Σ CP
1st term TUB	Higher Mathematics for Physicists I/II	Computer-orientiered Mathematics I+II		Scientific Information Management	Required Elective (Recommendation: Society)					
CP	10	8		6	6				30	30
2nd term TUB	Higher Mathematics for Physicists II/I	Computer-orientiered Mathematics I+II		New Media in Education and Research						
CP	9	14		6					29	59
3rd term TUB	Higher Mathematics for Physicists III		Experimental Physics I		Required Elective (Natural Sciences I)	Elective (Recommendation: Intercultural Communcation, Language Course)				
CP	10		12		3	6			31	90
4th term TUB		Introduction to Numerical Mathematics	Experimental Physics II		Required Elective (Natural Sciences II)	Elective (Recommendation: Project Management)				
CP		10	12		3	6			31	121
5th term abroad				Instruction with Media	Required Elective (Natural Sciences III, IV)	Elective (Recommendation: Language Course)	Teaching Activitiy in Natural Sciences			
CP				8	12	6	4		30	151
6th term abroad				Project Management	Required Elective Seminar Paper (Multimedia project enriching a course)	Elective (Recommendation: Society and Culture [o.t. host country])				
CP				8	16	6			30	181
7. term abroad or TUB					Required Elective (Natural Sciences V-VIII)		Vocational Training (12 weeks)			
CP					24		6		30	211
8th term TUB					Required Elective (Natural Sciences IX)	Elective (Recommendation: Vocational Preparation by TUB-Career-Service)		Bachelor Thesis		
CP					11	6		12	29	240
	CP in required courses 113 CP ≈ 47%				CP in required electives 75 CP ≈ 31%	CP in elective courses 30 CP ≈ 13%	CP vocational prep. & bachelor thesis 22 CP ≈ 9%			

Fig. 1 Exemplary courses for the Bachelor+ programme NATURAL SCIENCES IN THE INFORMATION SOCIETY

The selection criteria particularly depend on above average achievements during the study, the motivation for a stay abroad as well as on already existing knowledge of the partner country and the national language. In the context of their study at TUB the students must have completed the necessary basics from the required courses well above average. Above all the students are to bring in their own technical and metadisciplinary knowledge and educate themselves further both interculturally and technically. On the one hand the students have to strengthen their knowledge within the "Required Electives" list and "Electives" courses technically and on the other hand select modules as preparation for their stay abroad. For the preparation modules from the "Required Electives" list, especially society as well as language courses and modules for project management or intercultural communication serve according to the regulations of the study guidelines.

The number of places available is 4 per academic partner, totaling in 8 (2 academic partners for 2011), with a class strength of 30 students.

In the context of the preparation for the year abroad, guest lecturers from the partner universities are invited and their lectures blended into the regular courses. The organisational support of the programme coordinates the visits of the guest scientists. Regular video conferences are one component of the exchange of the workgroups.

With 49 % the ratio of women in the programme fulfills the expectations of the programme developers and in the higher terms the achievements of the female students are better compared to those of the male students. This is characterised by one female "German National Academic Foundation"[4] scholarship holder and female fulltime Fulbright scholarship holder. Furthermore, the desire for a year abroad was expressed by the majority of the female students during their mentoring discussions. Now, the mentors will specifically advertise the programme to female students. Thus, we expect that predominantly female students apply successfully for a scholarship in the context of the BACHELOR PLUS programme. Cooperations with other TUB projects, e.g. "Zielgerade" [Berb] and "IMPETUS" [Bera], exclusively promoting female students are also mentioned, and are well-known and actively used by some individual students. In the selection and matching process a relevant influence is given to the motivation of the students.

4 Content and Goal of the Year Abroad

4.1 Content

The year abroad is scheduled for the fifth term (cf. Fig. 1). During at least two terms abroad the students have to attend the two further required courses "Project Management" and "Instruction with Media" to the extend of 16 CP according to ECTS. "Project Management" strengthens international professional qualification while the goal of "Instruction with Media" is to sensibilise the students for the requirements and handling of media and strengthens their competencies in this field.

During their stay abroad students have to attend courses from the list of required elective courses to the extend of 28 CP from the fields of natural sciences and technological disciplines, basing upon their present skills. Here, students participate in at least two courses with their local fellow students. Thereby an intensive exchange between their own technical skills and the learning and teaching methods from TUB is initiated. Here, students also have to prepare a seminar work to an extend of 16 CP. This term paper serves for self-reflection of technical content in another language and has to be designed as a multimedia project.

[4] Studienstiftung des deutschen Volkes

The elective domain (12 CP) shall provide for the individual cultivation of a competitive profile. Here, we recommend students to attend courses that enlighten their insight to the culture and society of their respective host country. Students have to impart their technical knowledge in terms of some teaching assignment, e.g. in a tutorial for local freshmen. Therefore, an amount of work equivalent to 4 CP is determined. Experiences from the teaching assignment shall later be integrated into the term paper.

During their first semester abroad students attend a required lecture about “Instruction with Media” and have to delve into natural sciences and technological subjects. Moreover, we highly recommend attending a language course. Furthermore, the students are integrated into their host universities by their support for students in lower terms, technically and multimedia-based. Thus, they gain some first insight to the procuration and demonstration of technical content. Finally, the students are also integrated in the workgroups and the working environment of their workgroups. The visiting lecturers shall be members of these workgroups and establish contacts to the students at TUB before their mobility period.

During their second term abroad “Project Management” is the only required course, additionally to one elective course (e.g. culture and society of the host country). Moreover, the students write their term paper in their host-workgroup. Goal of this work is the multimedia based and if applicable didactical preparation of a lecture from the natural or engineering sciences. Here the students’ technical German background and their experiences from their first term abroad come to play. The required material for the application in the lessons is to be provided by tangible means of the project. One exemplary project is outlined in the following section.

4.2 Goals

Transfer of knowledge is one of the main components of the project. The students are integrated in teaching and research at their host universities. Project work in their workgroup and the concurrent media-didactical preparation in a foreign country lead to an international professional qualification. Supervision of the students is taken care of in the workgroups and via phone, eMail, video-conferences and by the mentors from TUB.

5 Multimedia Based Preparation of a Lecture by Means of the LiLa-Project

The LiLa project – acronym for “Library of Labs” – is a project to network remote experiments and virtual laboratories funded by the European Community. Aim of the project is the buildup of a Europe-wide infrastructure for the mutual use of experimental structures and simulation software for improving the teachings in basic studies and/or at the undergraduate level of scientific academic subjects. Hands-on courses are – in addition to lectures – one of the fundamentals of engineering education. Students learn here how to solve practical problems, and delve into experimenting with real equipment. Besides theory and practical experiments, simulations also become relevant in science and engineering; increasing costs force engineers to substitute expensive or complex experiments by simulations – sometimes not even to cut costs, but also to gain insights not or only hardly achievable due to physical constraints otherwise. Remote Experiments are available over the internet by construction, an obvious improvement of this situation is to found a federation of supporting institutions, and allow students mutual access to the equipment available in this federation in total: This is the major goal of the LiLa project, namely to setup a Library of Laboratories across Europe, and to share resources available in this network. LiLa is funded by the European Community by its eContent*plus* programme [Soc11].

However, goals of this project go beyond generating the software necessary to setup said network: its aim is not only to share and increase the utilization of the equipment, but also to help students to find the experiments they need, to integrate the experiments into electronic library catalogs, to link them to "traditional" media as for example lecture notes, and to equip and extend the experiments by courses build from this media; last but not least, an important further goal of LiLa is to integrate such interactive courses into the curricula of universities.

5.1 Remote Experiments

The first type of content made accessible by the LiLa network is that given by "Remote Experiments": A remote experiment is an experimental setup controlled by a common PC; by appropriate software – typically LabVIEW [Ins] by National Instruments – sensor data and control parameters of the experiment are made accessible over the internet. Remote experiments are already deployed at TU Berlin (Germany), the University of Cambridge (United Kingdom) and Basel (Switzerland). Cf. Fig. 2 for an experiment from thermodynamics run at TU Berlin.

5.2 Virtual Laboratories

As opposed to remote experiments, virtual laboratories are simulation frameworks that run on the computer only not interacting with a physically existing experiment. Even though one could simply ask students to install the simulation software on their home PC, we prefer to use a client-server model here as well. First of all, the amount of work for installation is minimized, and second – but even more important – the server architecture allows students to interact with each other and with teaching staff and collaborate on one simulation. An example for a virtual lab-

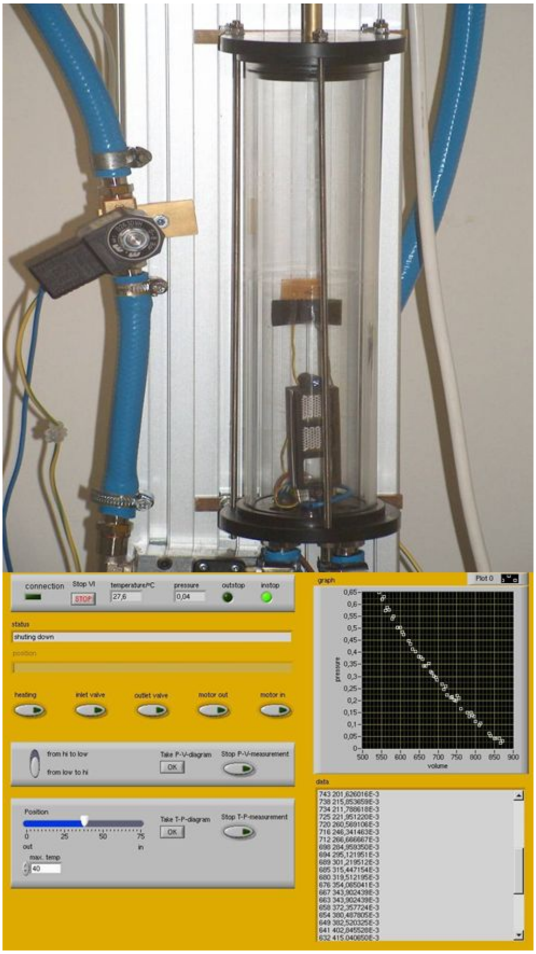

Fig. 2 Remote experiment on phenomenological thermodynamics. The piston compresses air in the glass cylinder; a heater below controls the air temperature. Pressure and temperature are measured on the PC. The LabVIEW user interface of this experiment is depicted at the *bottom*

oratory is VIDEOEASEL that has been developed at TU Berlin and at the University of Stuttgart. VIDEOEASEL is a simulation framework for experiments in multi-particle physics. Further virtual laboratories are provided by the universities of Basel, Cambridge, and Linköping (Sweden).

The most comprehensive work package of the LiLa project is managed by TU Berlin. In this work package already existing content (virtual laboratories and remote experiments) are integrated into the LiLa platform, where content is not only understood to consist of interactive experiments, but also includes "more traditional" material like lecture notes and scientific publications. In this work package a design a meta-data set suitable for the annotation of interactive material has been

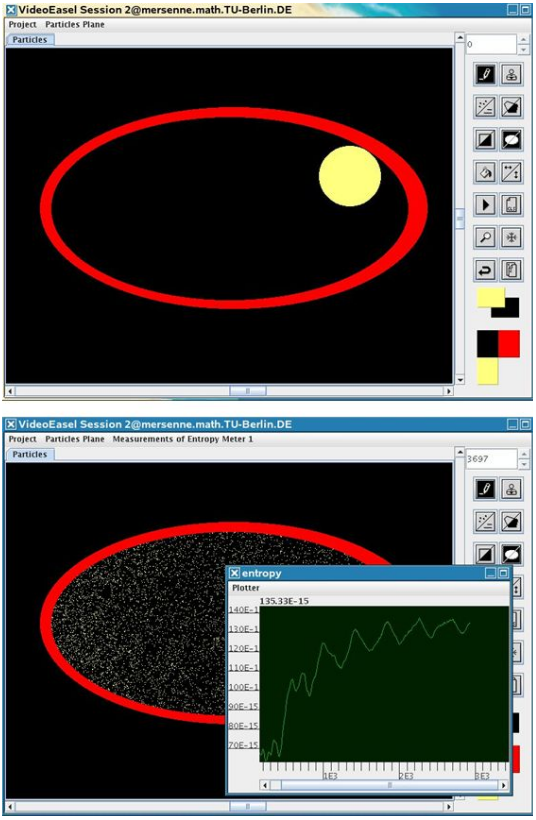

Fig. 3 Virtual experiment concerning the second law of thermodynamics. The initial state of a gas (*yellow*) in one confined area of the container (*red*) is depicted on *top*. The final distribution of the gas after running the experiment for some time together with the entropy over time is depicted at the *bottom*

also developed. Enriching a traditional lecture with the possibilities offered by the LiLa project is one potential candidate for a student's project abroad. Moreover, it offers further cooperation possibilities for the teaching staff involved.

6 Organisational Regulations

The accreditation of the study achievements is guaranteed by a learning agreement on basis of a list courses, that have to be attended and a list from which students may choose. The acknowledgment confirmation is issued on the basis a learning certificate that is issued by the host university, in arrangement with the home university. The range of the free choices makes adds additional flexibility to the accreditation process. It is a principle that the acquired achievements are evaluated as larger units and not as punctual individual parts. The list of courses is continuously extended and is an important component of the agreements between the partner universities. At the latest at the beginning of the first term abroad written agreements are present.

The curriculum is addressed towards future students as well as to students enrolled in the second term. For students, enrolled before the winter term 09/10, the year abroad is also to be made possible (including the preparation for the foreign stay). The anchorage for these students is to be offered as auxiliary qualification starting from the sixth term.

All students may supplement the one year's stay at their host university optionally by a further term, in which an additional occupation orientation takes place. In particular the already integrated vocational training course can be completed abroad. The same holds true for the bachelor thesis, if at least one reviewer at TU Berlin approves.

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Experiences from an International Student and Staff Exchange Program

Sabina Jeschke, Nicole Natho, Olivier Pfeiffer, Erhard Zorn

Abstract We describe an ongoing exchange program between 11 universities from the European Union and candidate countries and 9 universities form Jordan, Lebanon, and Syria, implementing a bilateral mobility flow between the European and the neighbouring countries. Experiences are reviewed, including the not exclusively academic obstacles that we had to overcome in teaching and learning within these different educational systems.

Key words: International Student Exchange, ECTS, Bologna

1 Background

Initially, the idea of this project intended to focus on Information and Communication Technologies (ICT) related subjects only, it was extended to students from all areas of studies. Anyway, the majority of all participating students, at least at our university, are from technological disciplines.

The described programme encompasses all levels of tertiary education: (under-) graduates, PhD-students, postdocs and academic staff. In addition to broadening their technical education, all participants benefit from the re-evaluation of their own culture that occurs while working as part of another culture and communicating a foreign tongue. During the three stages of the Erasmus Mundus External Cooperation Window Lot3 (later Lot4) more than 300 scholarships have been awarded, with TU Berlin participating in approximately 1/6 of these mobilities (incoming and outgoing).

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A part of the scholarships at the graduate and undergraduate level was granted to credit-seeking students. The remaining of the graduate, undergraduate and all PhD-scholarships were awarded to degree-seekers. Surprisingly for us and the Arab students, one of the challenges that showed up was that accrediting a degree obtained from some European university turns out to be much easier than getting a credit for a lecture attended at the very same university.

The cause quickly turned out: on the European side, as a consequence of the Bologna Process all European universities use the ECTS (European Credit Transfer and Accumulation System) as the standard for comparing performance and achievement of students. While on the Arab side, the American academic system (or similar to it) is used in all partner countries. In fact, one of them is an American University, i.e. the degrees awarded are officially registered by the Board of Education in New York State.

2 Overview of the Erasmus Mundus Action 2[1]

The Erasmus Mundus External Co-operation Window (EM ECW) which has become part of the regular Erasmus Mundus programme (EMA2) in the beginning of 2009 is a cooperation and mobility scheme within the area of higher education. The EM ECW was launched by the Europe Aid Co-operation Office in 2006 and has been implemented by the Education, Audiovisual and Culture Executive Agency (EACEA) of the European Union ever since.

Aim of the EMA2 is to strengthen the ties between higher education institutions in the European Union and in partner countries that are not part of the European Union. Specifically, the EACEA and EM ECW aim "to enable students to benefit linguistically, culturally and educationally from the experience of pursuing academic studies in another country, and to promote European Union (EU) values; to improve the transparency and recognition of studies and qualifications, in particular building on the 'acquis' and achievements gained of the Bologna process in this area; to enhance the skills and qualifications of foreign higher education staff so that they can contribute actively towards improvement of quality; to build the capacity of the administration and public and private sector by participation of their staff in higher education mobility activities (especially through doctorate and post-doctorate activities" [Com11]. To achieve this, student and academic staff exchanges are sponsored in order to promote the partnerships and institutional co-operation exchanges between the European and partner country institutions.

The European Commission sponsors these partnerships with grants that partially cover the costs of the organization of mobility of higher education students and academic staff and the costs of the implementation thereof. On the European side, all 27 member states as well as the candidate countries and European Economic Area (EEA) countries are eligible to become partners in this project. Each non-EU coun-

[1] formerly known as "Erasmus Mundus External Cooperation Window".

try eligible for this project is part of a certain geographical lot which usually consists of countries which lie in close proximity to each other. The partnerships supported by EMA2 need to have at least five European higher education institutions of at least three countries whereas the required number of partner country participants differs from lot to lot. In the end, a maximum of 20[2] partners can be involved in each partnership. However, an unlimited number of associates can be added to the project. These associates contribute to the implementation of the mobility scheme but do not receive any funding from the EU through the project.

The mobility itself is divided into different target groups as well as different individual mobility flows: there are three target groups, i.e. scholars from the partner universities (target group one), scholars from other universities in the partner countries (target group two) and target group three that consists of scholars in particularly vulnerable situations such as refugees, asylum seekers, or individuals with disabilities. Scholarships vary in length between one month and 36 months and are given to undergraduate, master and doctorate students as well as post-doctorates and academic staff.

The project grant consists of flat rates (€ 10,000 per partner for mobility organization costs) and unit costs to cover the individual mobilities. EMA2 scholars receive a monthly allowance between € 1000 and € 2500. The costs for travelling, health insurance and tuitions fees are also covered by the scholarship.

Whereas the first call for proposals in 2006 provided funds with a total of € 36.4 million for projects in nine geographical lots, consisting of altogether 24 partner countries, the overall budget of projects awarded through the last call in 2008 amounts to € 163.5 million. The call for proposals in 2008 covered 21 geographical lots of more than 50 partner countries. The overall available amount under the recent call for proposals (December 2010) is approximately € 100 million, aiming at a minimum mobility flow of 3475 individuals. This is the second call in the Erasmus Mundus programme that also promotes student mobility to and from the highly industrialised countries (e.g. Australia, Canada, Japan, Singapore, South Korea, UAE, USA) with approximately 5 % of the overall budget. Thus, in theory every country in the world can participate in Erasmus Mundus today. However, this programme is accomplished in cooperation with the partner countries and they may choose other measures or dates. Therefore, the only country from Latin America that is covered in the current call is Argentina.

3 Implementation of the EM ECW TUB

Technische Universität Berlin (TUB) has been a part of the partnership for the geographical lot of Jordan, Lebanon, and Syria since the start of the programme in 2006. The calls were renewed in 2007 and 2008. Lunds Universitet is the coordinator of this project. Other European partners are Masaryk University in the Czech Repub-

[2] respectively 12 partners for strand 2

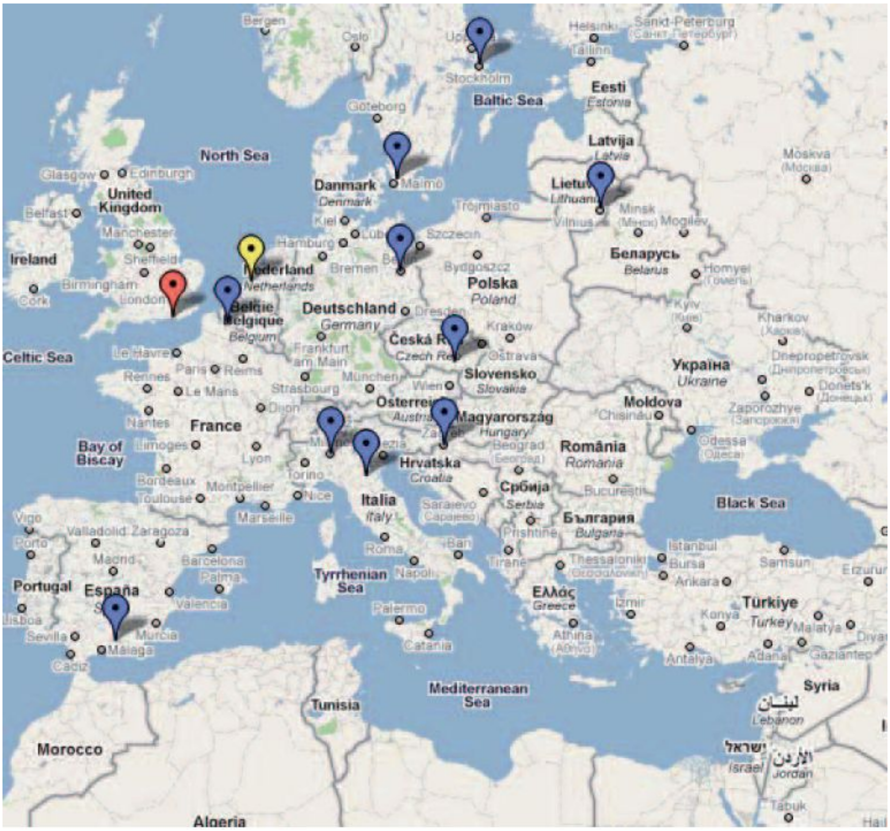

Fig. 1 Geographic Distribution of the European Partner Universities (*blue*: constant members, *red*: leaving member, *yellow*: joining member)

lic, University of Granada in Spain, Lille University of Science and Technology in France, University of Bologna and Catholic University of the Sacred Heart in Italy, Vilnius University in Lithuania, Royal Institute of Technology (KTH) in Sweden and University of Zagreb in Croatia. One of the original partners from the United Kingdom was later substituted by University of Leiden from the Netherlands. Please see Fig. 1 for the geographic distribution of the European partner universities.

The European partners are joined by higher education institutions from the Middle East: five Jordanian universities (University of Jordan, Jordan University of Science and Technology, Princess Sumaya University for Technology (PSUT), Tafila Technical University, and Hashemite University), two Syrian universities (University of Aleppo and University of Damascus) and two Lebanese universities (Lebanese University and American University of Beirut). Please see Fig. 2 for the geographic distribution of the Arab partner universities.

18 % of all mobilities have gone to TUB in the first three years of the project. When it comes to doctorate candidates, every fourth scholar has been sent to TUB. If

Fig. 2 Geographic Distribution of the Arab Partner Universities (*green*: Syrian Universities, *red*: Jordanian Universities, *purple*: Lebanese Universities)

one has in mind that TUB is just one of eleven European partners, the predominance of TUB becomes immediately obvious. This discrepancy is more apparent in the first two phases of the project and is being corrected in phase 3 in which only seven scholars have been sent to TUB.

Although this partnership came into being due to an earlier cooperation between these universities in the field of ICT, the EM ECW does not focus solely on ICT but was soon opened up to all academic fields. Nevertheless, the better part of all participating students is still from computer sciences and engineering disciplines. 42 % of the scholars took classes or did research in one of the engineering departments at TUB.

The funds for the implementation of the mobility (monthly scholarships, costs for health insurance and travel grants) are transferred to the bank account of TUB where it is the responsibility of the administrative staff to disburse these payments to the respective scholars. Since these administrative tasks were adding to the usual workload of the staff at TUB, an advisor for all matters related to the EM ECW/EMA2 programme is now in office. Through this individual, TUB provides all services that are necessary to implement the mobilities, such as issuing visa invitation letters, enrolling the students at the university, arranging for health insurance coverage as well as travel to and from Berlin.

4 Highlights and Potential of the EMA2

The most positive aspects of the EMA2 programme are the broadening of the participating scholars' educations as well as the re-evaluation of one's own culture that occurs when one is living within a different cultural surrounding than the one used to. Students from this EMA2 have an Arabic background which usually also means that they have the Muslim faith. Moving to a western central European country serves as a culture shock for many of them. Not only do they have to learn another foreign language – not all Germans speak English – but they also have to get accustomed to a different way of life. Often, they find a path of their own between the Arabic culture they are used to and the European way of life: A female Jordanian student refused to live in a mixed dorm where female and male students lived. Therefore, she moved into her own apartment that was located off-campus.

Due to participation in the EM ECW program, TUB was able to strengthen its ties to the Middle East. Especially co-operations with Jordanian universities have been intensified and TUB has applied with two of the Jordanian EM ECW partner-universities on a Trans-European Mobility Scheme for University Studies (TEMPUS) project this year. Moreover, TUB and PSUT will start a mutual student exchange this year.

The challenges of the project refer to the differences between the European and Middle Eastern educational systems. Whereas the majority of the classes at Middle Eastern universities are taught in Arabic, a substantial numbers of classes are also offered in English. Several students who came to TUB as EM ECW scholars were surprised to find out that about 95 % of the programs offered here are taught in German. Currently, there are only six master programs that do not rely on knowledge of the German language. For all others, students need to prove that they know German on a certain level; they even need to pass state-wide examinations such as the German Language Test for Universities (Deutsche Sprachprüfung für den Hochschulzugang, DSH) before they can enter degree programs. Due to this unawareness, several of the scholars attending TUB have to take language classes to improve their German skills.

Regel [Reg92] claims that "because of its large, flexible, and complex academic system, because English is the main language of communication, because many of the key journals and publishers are in the U.S., and because many scholars and policy-makers have studied in the United States, the American system is a powerful attraction" which, he later admits, is not readily exportable. The same applies for the ECTS. In this case, however, the ECTS and American credit system collide and the EM ECW/EMA2 scholars are the ones who suffer. While the Middle Eastern countries adopted the American system for the above mentioned reasons, it complicates the EM ECW/EMA2 exchanges to a certain extent. More flexibility of both home and host universities in accepting credits obtained at the other institution would be really helpful for the students and the future of the program.

According to Van Damme [VD01], "one of the most serious problems in policies and programs aimed at increasing international mobility surely is that of the recognition of study periods and credits obtained abroad. [. . .] The lack of transparency and 'readability' of higher education regulations at national, but also at institutional and sometimes even faculty levels creates all kinds of problems, resulting in a widespread uncertainty among students about the recognition of a credit or the study period in the home university. [. . .] Automatic transferability of credits among countries even with a rather similar educational system still is a dream."

This is exactly what we experienced at TUB: a part of the scholarships at the graduate and undergraduate level was granted to credit-seeking students who were essentially exchange students. The rest of the graduate, undergraduate and all PhD scholarships were awarded to degree-seeking students, i.e. those students who came to Berlin not to finish a degree they had started at their home universities, but to start a completely new program. One of the challenges that appeared was that, surprisingly for the Arab students and us, accrediting a degree obtained from some European university turned out to be much easier than getting a credit for a lecture attended at the very same university.

The cause quickly turned out: on the European side, as a consequence of the Bologna Process all European universities use the ECTS (European Credit Transfer and Accumulation System) as the standard for comparing performance and achievement of students. While on the Arab side, the American academic system (or similar to it) is used in all partner countries. In fact, one of them is an American University, i.e. the degrees awarded are officially registered by the Board of Education in New York State.

5 Future Developments of the Program

In late 2009 the EMECA (Education, Audiovisual & Culture Executive Agency) [Com] announced changes in the Erasmus program. Since 2010 the EM ECW is part of the Action II of Erasmus Mundus program (EMA2). Within this change the geographic outreach of the external cooperation has been broadened, now covering almost every country, including Canada, Japan, USA, and the Gulf countries.

6 Conclusion

TUB has benefitted from its participation in the EM ECW programme with Jordan, Lebanon, and Syria, and has been a dedicated partner from the start of the program. However, the financial aspect of the project should not be overlooked: Although the coordinating university receives € 10,000 for each participating university, less than a sixth part is actually transferred to each partner. This share is supposed to cover the administrative expenditure for the duration of this four year program. At the same time, additional costs such as language-classes are to be financed by means of this so called lump sum. In the end, each partner has to be prepared to dedicate a lot of manpower in this project. This can be considered the co-financing in this programme. However, every university considering to join an Erasmus Mundus Action 2 partnership should consider if and how the financial expenditures can be covered to ensure a swift accomplishment before signing the associated partnership statements.

Summarizing, the positive aspects of joining any EMA2 programme outbalance the financial expenditures. Any student who is able to receive a better education or broaden his/her personal horizon due to participating in an exchange and scholarship programme is a huge plus. In the future, though, more attention should be paid to the financing part of the mobilities as well as the obstacles that hinder the transfer of credits between universities in different systems of higher education.

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Work in Progress: Engineering Math with Early Bird

Sabina Jeschke, Olivier Pfeiffer, Erhard Zorn

Abstract Mathematics is the most important discipline for engineering students besides their own subject – and it is constantly required in engineering freshmen lectures. Sometimes, mathematical content is needed in engineering lectures before it has been taught in the mathematics classroom. Thus, the engineering teachers often have to do mathematical excurses that are ineffective and unsatisfying, both for the students and the teachers. A propaedeutic dedicated to mathematical studies only, cannot be implemented within the current study regulations. Moreover, it would contradict the engineers' wish for a rapid identification with the "real" engineering subject to increase the students' motivation. Therefore, we introduced EARLY BIRD to overcome this deficiency. In EARLY BIRD I freshmen can benefit of their time between high school graduation and their enrollment at the university to attend Calculus I and Linear Algebra classes. In EARLY BIRD II Calculus II classes are offered during the winter semester break.

Key words: Bridge Course, Engineering Mathematics, Propaedeutic, Undergraduate Students

1 Background

Mathematical comprehension and proficiency are some of the most important utensils of engineers and are constantly required in engineering freshmen lectures. Sometimes, mathematical content is used in engineering lectures before it has been

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taught in the mathematics classroom. Thus, the engineering teachers often have to do mathematical excurses that are ineffective and unsatisfying, both for the students and the teachers.

A propaedeutic dedicated to mathematical studies only, cannot be implemented within the current study regulations. Moreover a propaedeutic would contradict the engineers' wish for a rapid identification with proper engineering content to prevent a motivation drown that incorporates various service modules, thus leaving only little room for the "real" subject.

Many universities are offering "bridge courses" or preparatory courses to bridge the gap between high school and university. At least at German universities, as far as the authors know, these are additional courses and they are intended as a repetition of the subjects that (should) have been learned at high school. Additionally, some courses are designed to give the freshmen the opportunity to discover their strength and weakness [Bud95].

Thus, these bridge courses are not solving the "conflict" between the engineers' wish to start as early as possible with the engineering subjects and the mathematicians who want to teach mathematics starting with the fundamentals, not with the subject needed in the engineering classes at the beginning.

2 Early Bird I

Starting winter semester 2006/07 we offer the Early Bird I course for engineering freshmen before their enrollment at the university. This is a 9 weeks course with a two hours daily lecture, a one hour daily recitation class, and daily assignments. During this course, Calculus I and Linear Algebra are taught with the same amount as in the regular courses. In this course, both the number of lectures and the number of recitation classes corresponds to the number of the regular courses. And the students have to qualify for the final examinations by attaining 50 % of the assignments as well.

The course is offered for 20 % of the freshmen in engineering studies (400–450 participants), and in general there are more applicants than positions available. The workload of the students is very high and there is not much time to relax. Therefore, the demands on applications are as follows:

- High dedication and endurance
- Willingness to concentrate on mathematics for more than two months
- Regular participation in daily lectures
- Regular and active participation in daily recitation sessions
- Regular and thorough solution of daily assignments in two-person-teams.

On the other hand the advantages for the students are as follows:

- The students benefit of their time between high school graduation and their enrolment at the university.

- The students can concentrate on mathematics without any “distractions” by other courses.
- The students learn the mathematics used in engineering classes for freshmen in advance.
- The students benefit from smaller recitation classes limited to 16 participants (in regular courses the limit is between 25 and 35).
- The students become acquainted with fellow students and form study groups that may persist during the next years.

The course starts during the summer semester break and it ends two weeks before the lectures of the winter semester start. The final examinations take place in the last week before the lectures of the winter semester start. In the week between the end of the Early Bird I lectures and the final examinations we offer a summer camp in a youth hostel in the vicinity of Berlin. In the loneliness far away from the metropolis of Berlin, together with the teaching assistants, the students can concentrate on mathematics and repeat the most important subjects of the lectures.

Early Bird I students are allowed to take the final examinations in Calculus I and Linear Algebra as a “free trial”, i.e. if they fail they still have three chances to pass the examinations. And if the Early Bird I students are not satisfied with their result they are allowed to repeat the examination.

3 Early Bird II

In their first semester, most of the Early Bird I students who passed the final examinations attend Calculus II, an obligatory course for all second semester engineering students. By this they still profit from their mathematical advances in their second semester. But there are some Early Bird I students who cannot attend the regular Calculus II lectures in their first semester due to a timetable adjusted to students starting the mathematics courses in their first semester. For these students we offer an Early Bird II course. The structure of this course is similar to the Early Bird I course: This is a 6 weeks course with a two hours daily lecture, a one hour daily recitation class, and daily assignments. During this course, Calculus II is taught with the same amount as in the regular courses. In this course, both the number of lectures and the number of recitation classes corresponds to the number of the regular courses. And the students have to qualify for the final examinations by attaining 50 % of the assignments as well.

All students can apply for Early Bird II under the condition that they successfully passed Calculus I. This course has been offered every year since spring 2007 for 10 % of the students in the regular Calculus II course in summer semester (100–150 participants). Not all students of Early Bird II participated in Early Bird I; there are also “regular” students who want to use the opportunity to successfully complete their mathematics courses during the spring semester break and concentrate on their engineering subjects afterwards.

4 Results

Both Early Bird courses have been carried out several times successfully since summer 2006 and spring 2007, respectively. The grades of Early Bird students are above average and both students and teachers/teaching assistants are very satisfied. 99 % of the Early Bird I students are recommending this course to other prospective engineering students.

The teachers/teaching assistants perceive a high motivation and a pleasant spirit during both courses which is extremely rare in such big courses. The participants are highly motivated and extremely ambitious, on the other hand a very familiar atmosphere develops during the courses which motivates both students and teachers. Teachers/teaching assistants are fulfilling their mandatory teaching assignments during the semester breaks. Therefore, in the following semester they are freed of duties and they can spend time on their own research.

5 Conclusions

Both freshmen and teachers appreciate the Early Bird courses and profit by learning and teaching mathematics in a very concentrated way. Nevertheless it should be kept in mind that the courses are very strenuous for both teachers and students. Therefore, only very ambitious and powerful students should be encouraged to attend such intensive "bridge courses". On the other hand the Early Bird courses provide an opportunity to utilize lecture halls and recitation rooms during the semester breaks.

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A Management Approach For Interdisciplinary Research Networks in a Knowledge-Based Society – Case Study of the Cluster of Excellence "Integrative Production Technology for High-Wage Countries"

Claudia Jooß, Florian Welter, Anja Richert, Sabina Jeschke, Christian Brecher

Abstract Due to globalisation, innovations in low-wage countries take place in increasingly faster cycles for several years. By this means, the pressure on high-wage countries rises in order to keep up their knowledge advantage within diverse branches. Because of the fact that new knowledge is established more and more among interfaces of various disciplines, different demands arise with regard to an adequate institutional framework. Thus, the nationwide initiation of so-called Clusters of Excellence in Germany can be classified as a measure which has the target to support innovation activities within knowledge intensive networks. However, highly complex and heterogeneous research networks are in need of an appropriate management approach which supports the cross linking of various disciplines and increases the scientific output, but a corresponding approach is not established yet. Therefore, the so-called Cross Sectional Processes in the Cluster of Excellence 'Integrative Production Technology for High-Wage Countries' at RWTH Aachen University, Germany, aim at creating management approaches to fit the needs of huge, heterogeneous, highly complex and dynamic research clusters. Moreover, the aim of the investigations is to design, implement and evaluate a management approach transferable to similar clusters and networks in future in order to foster interdisciplinary innovation activities in networks.

Key words: Interdisciplinary Research Networks, Innovations, Cross Sectional Processes, Management, Knowledge-Based Society

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1 Path to a Knowledge-Based Society and Increased Innovation Activities in Networks

Nowadays knowledge constitutes the most important factor of success for highly developed economies of the world apart from classical factors of production such as work and capital. For many years the successful economic development was based on these factors which were available sufficiently at favourable conditions. In particular the factor 'work' is characterised by an increase of costs due to a progressing economic development of a country and an increasing social prosperity (in terms of rising incidental wage costs). Therefore the modern industrialised countries, including Germany, can be referred to as high-wage countries. The increasing labour costs cause the relocation of companies into countries with cost-advantages in production of goods or services. Thus, in the last decade several production relocations into emerging and developing countries took place, which can be classified as low-cost-countries on the world market [SOK07].

In the course of this development other factors of production did not replace the conventional ones, but contributed to a reweighting of all factors of production. With reference to the latter, the generation and control of highly complex knowledge provides locational advantages, especially to high-wage countries. These advantages are decisive for knowledge-intensive enterprises and research facilities to remain with their enterprise or institution in high-wage countries or to (re-)locate again into a high-wage country. Parallel to this development, emerging economies increase their innovation-activities (e.g. the republic of China) so that the competitive pressure on high-wage countries rises [bal08]. Without the continuous generation of new, highly complex knowledge it is impossible for all high-wage countries to bear up their economic and technical market leadership in various sectors. Hence, possible strategies of action suggest additional investments in education and research, the development of flexible production and organisation processes as well as a more intensive orientation towards knowledge regions[1] [Bus05, Fro08]. The necessary paradigm shift within the society – from an industrial society to a service society towards a knowledge based society [Hee02, RB05] – hence mirrors Germany's current research policy, too. The crucial character of this new knowledge based society thus depicts the creation of capital through creative and productive workforces – so-called "Brainworkers" [HIR08]. A step into this direction represents the Excellence Initiative[2], established by the German federal government in the year 2005. The initiative intends that the best universities shape and deepen their areas of competence and/or develop new interdisciplinary research co-operations by additional public

[1] After Buschmann (2005) a knowledge region can be defined as a region which concentrates on measures to foster the future viability of the region through a conscious consideration of the knowledge perspective. Furthermore, these regional efforts have to be perceived internationally.

[2] The Excellence Initiative is divided into three lines of funding: *Graduate Schools, Clusters of Excellence and Institutional Strategies* in the context of excellent university research.

funding. In doing so, Germany's best universities shall take over the role of "lighthouses" [exz09] in the international scientific community in future. One section of the Excellence Initiative includes the foundation of so called Clusters of Excellence at German universities, which can be characterised as highly complex networks of scientific actors following a common vision.

2 The Structural Challenge of the Interdisciplinary Research Networks

The superior task of the Cluster of Excellence 'Integrative Production Technology for High-Wage Countries' at RWTH Aachen University is the development of a holistic theory of production in high-wage countries. Hence, the approach is embedded in a production strategy integrating the knowledge of scientific actors as well as industrial actors. Because of this, nineteen chairs at RWTH Aachen University (especially of production engineering and material sciences), seven affiliated institutes and other advising industrial partners are researching on this common vision since 2006. This research shall culminate in the resolution of the polylemma of production in future (cf. Fig. 1) [fH07, BHK^{+}08].

Due to its dimension and complexity the Cluster of Excellence is larger than a conventional research project, e.g. a collaborative research centre[3] and therefore it has to cope with other structural and organisational challenges. According to Sydow (2001) the Cluster of Excellence can be assigned to the type of "project networks". This kind of network is described by a majority of authors as an exceptionally advantageous constellation for production, transfer and use of knowledge and information. Furthermore it is characterised as a knowledge intensive organisation, which is able to develop and exploit superior knowledge [HOI03, HS03, KM03]. A project network is initiated by current research and development (R&D) needs as well as other economic and political needs[4]. Concerning these needs, the expectation on its innovation abilities or the realisation of its vision is comparatively high [Syd01]. The high peer pressure implies tailor-made management structures, which ensure an effective collaboration of the heterogeneous actors. Against this backdrop the Center for Learning and Knowledge Management and Institute of Information Management in Mechanical Engineering (ZLW/IMA) of RWTH Aachen University is assigned to network and connect the learning and knowledge processes within the Cluster of Excellence by means of the so-called Cross Sectional Processes.

[3] Collaborative research centres are applied for a project period of up to twelve years. In this period scientist cooperate beyond their respective subjects, institutes, research areas and faculties on a common research topic [For].

[4] Sydow (2001) differentiates between four network typologies: *strategical networks, regional networks, project networks and virtual enterprises.*

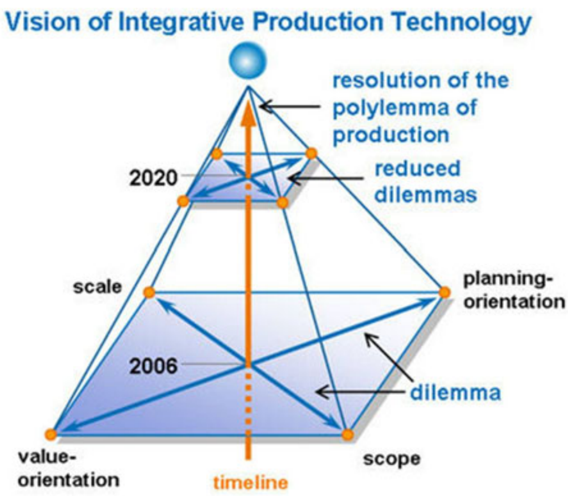

Fig. 1 Vision of Integrative Production Technology

3 An Approach for Interdisciplinary Cross-Linking: The Cross Sectional Processes

The Cross Sectional Processes approach particularly refers to the interlinking of actors and sub-projects of the interdisciplinary research network. Because of this, the Cross Sectional Processes (Integrative Cluster Domain F) occupy a superior position within the organisational structure of the Cluster of Excellence (cf. Fig. 2).

To enhance the development of the network, Cross Sectional Processes comprise areas like Scientific Cooperation, Education and Lifelong Learning, Equal Opportunities and Diversity Management as well as Knowledge and Technology Transfer. Hence, on the different levels of scientific collaboration (Knowledge Organisation, Research Organisation, Communication and Knowledge Output) various measures are implemented. The Research and Knowledge Organisation includes measures e.g. to increase the transparency of the scientific processes and to promote the exchange and satisfaction among all employees. This happens inter alia with the help of regular colloquia for research assistants or strategy workshops for leading researchers and members of the executive board. Concerning the task Knowledge Output the execution of a summer school depicts another important measure. Thereby not only cluster-internal cross-linking will be strengthened, but also international networking with other researchers. Furthermore, it behooves to the Cross Sectional Processes to create a cluster-specific management framework so that the performance of the entire Cluster of Excellence can be evaluated periodically. This proceeding allows to derive adequate recommendations for action. Thus, to gain an overview on the status quo (and to steer the network if necessary)

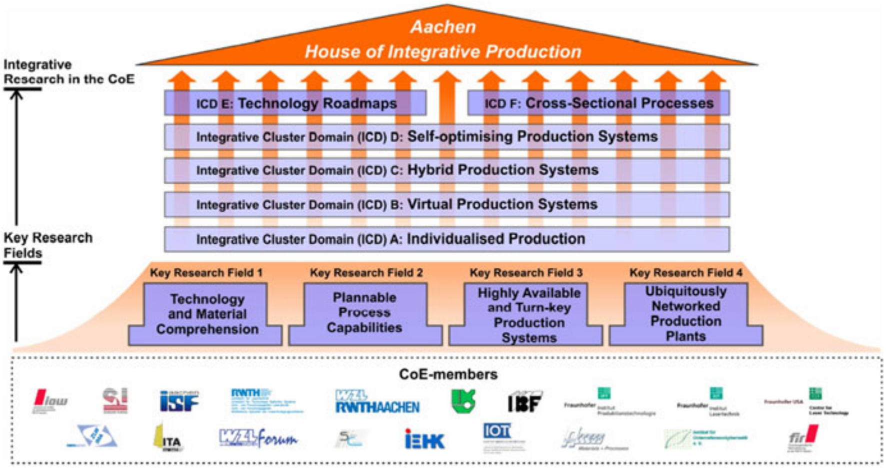

Fig. 2 Aachen House of Integrative Production

the execution of a yearly Balanced-Scorecard-based evaluation is an important approach. With regard to the latter, on the one hand the last evaluation showed an increased transparency according to scientific contents, on the other hand the evaluation revealed a further need for development concerning scientific cooperation. Moreover, the coordination and regulation of cross-linking tasks requires specific practices of management in terms of recurring actions to reproduce and update structures [Syd01, OSW97, Sau05, Win02]. Referring to this, practices and measures are developed and updated continually by an Inductive-Deductive-approach within the Cross Sectional Processes (cf. Fig. 3).

The Inductive-Deductive approach alternates iteratively between phases of application, investigation and organisation. By this means measures already introduced can be adapted to actual needs of the knowledge intensive organisation Cluster of Excellence. As an example of this proceeding, the first phase of performance measurement with the Balanced-Scorecard-based evaluation was reflected and specified in a workshop with participants of the executive board after the first cluster-wide implementation. A further actual adaptation represents a more integrative alignment of the colloquia for assistants. Thereby the initial focus will switch from an (in-)formal networking and transfer of information to an increased initiation of communities of practice as a form of voluntary working groups with specific research topics.

In order to respond to the question of transferability of a cross-sectional application model to similar knowledge intensive networks, all implemented measures are evaluated directly and indirectly within an accompanying research project. After the evaluation all collected data is analysed qualitatively in accordance to the "Grounded Theory" [GS08], a method of constant comparison. With reference to the continuation of the nationwide Excellence Initiative in the coming years, the generation of an application model is promising, because there is a huge demand for research concepts in the field of cross-sectional management.

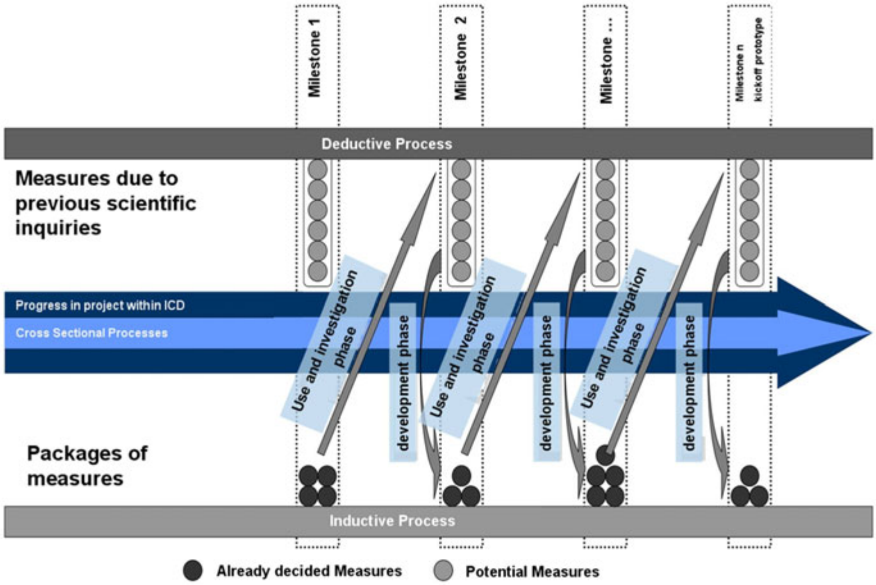

Fig. 3 The Inductive-Deductive Approach

Derived from the results of the first evaluation, a couple of cross-linking measures occur as particularly essential in the initial phase of a highly complex research network. These measures comprise e.g. the execution of colloquia for assistants, strategy workshops or advanced training for employees. With the introduction of these measures, the network can early be transported into a phase which is characterised by an increased scientific output[5]. Additionally the importance of the Balanced-Scorecard-based evaluation seems to increase with the maturity of knowledge intensive networks, because the network performance can be measured with this tool regularly. Thus it becomes possible for the board of management to steer the network into another direction, if necessary. Apart from that, the staff turnover in the Cluster of Excellence has to be highlighted as a remaining cross-linking challenge. Due to the fact that e.g. graduating university staff obtains mainly contracts for a limited period of time, staff turnover in university environments is relatively high. Regarding this, suitable measures need to be evolved to handle the fluctuation.

4 Summary

With the nationwide Excellence Initiative, new institutional framework conditions for science have been created by the German government. Referring to this, the Excellence Initiative fosters necessary changes in areas such as pillarisation of basic

[5] Ahrens et al. classify phases of network development in *initial phase, stable phase* and *steady phase* [AFF$^+$04].

research, applied research and operative R&D towards a dynamic-interactive process of interdisciplinary knowledge generation. With the Cross Sectional Process approach in the Cluster of Excellence 'Integrative Production Technology for High-Wage Countries' at RWTH Aachen University, a sound scientific application model for the management of knowledge intensive networks is being researched. The main objective of this approach is the effective interlinking of learning and knowledge processes by means of tailor made cross-linking measures related to the respective phases of network development. Hence the importance of an iterative proceeding has been highlighted with the implemented Inductive-Deductive approach. Furthermore, first research results imply a need for introducing measures which foster the transparency of scientific processes in the initial phase of a knowledge intensive network. In this way a more productive phase of the network can be reached. Parallel to that cross-sectional measures have to cope with a relative high staff turnover, which can negatively affect the flow of information among all cluster participants.

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The Challenge of Scientific Cooperation in Large Complex Research Clusters – Experiences from the Cluster of Excellence "Integrative Production Technology for High-Wage Countries"

Claudia Jooß, Florian Welter, Anja Richert, Sabina Jeschke

Abstract The initiation of so called Clusters of Excellence constitutes a milestone with regard to Germany's efforts to foster integrative and interdisciplinary research. Clusters of Excellence constitute spatially concentrated research networks including about 20 university institutes, non-university research institutes as well as further selected partners and advisors from industry and science.

The heterogeneity of the included actors can lead to structural, cognitive and cultural challenges in coordination and cooperation, because diverse disciplines (e.g. production and material engineering, informatics as well as business sciences) are integrated using different methodologies and technical terms. Therefore, the question arises in how far cross linked, knowledge-intensive and highly complex scientific cooperations can be organized to ensure a high quality of the research cluster output. To cope with the challenge of scientific cooperation, the conceptual framework of the Cross Sectional Processes in the Cluster of Excellence "Integrative Production Technology for High-Wage Countries" at RWTH Aachen University supports effective networking processes and strategic cluster development by means of learning and knowledge management. In order to contribute to the aforementioned research question, a model for the management of Cross Sectional Processes is developed. The model will define specific measures for a promotion of interdisciplinary cooperation and cluster development at respective phases of network development – e.g. from the initiation phase to the steady phase. Following the research approach of the Grounded Theory, the generation of the model bases on a triangulation of quantitative as well as qualitative data, captured through a Balanced-Scorecard-based performance measurement tool, direct evaluations and structured interviews with cluster members.

First results of the data triangulation make obvious that e.g. the role of project leaders as cluster-internal knowledge agents is crucial for a successful knowledge transfer in a hierarchical Cluster of Excellence. Moreover, a high rate of staff turnover in

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the research environment strongly influences the implementation of cross sectional activities. A further transfer of cross sectional measures to other forms of scientific oriented clusters and comparable networks is aspired by the Cross Sectional Processes to support scientific oriented interdisciplinary cooperation in future.

Key words: Challenge of Interdisciplinary Cooperation, Cross Sectional Processes, Learning and Knowledge Management in Clusters of Excellence, Model for Cluster Development

1 Background and Introduction

In order to overcome the pillarization of basic research, applied research and operative research and development (R&D) towards a more dynamic-interactive process of interdisciplinary knowledge generation, the German federal government initiated the Excellence Initiative to strengthen the research location Germany in a sustainable way.

In light of the German Excellence Initiative, one of the first scientific approaches for promoting interdisciplinary knowledge generation constitutes the Cross Sectional Processes in the Cluster of Excellence "Integrative Production Technology for High-Wage Countries". The approach aims at providing adequate measures of learning and knowledge management to support scientists working in interdisciplinary research areas. The main research question of the Cross Sectional Processes can be described with:

> How should cross-linked, knowledge-intensive and highly complex scientific co-operations within the Cluster of Excellence be organized and simplified to ensure the high quality of the cluster output?

As one of 37 funded Clusters of Excellence, initiated through the German Excellence Initiative, the Cluster of Excellence "Integrative Production Technology for High-Wage Countries" was established at RWTH Aachen University in 2006 bringing together interdisciplinary scientists – mainly from production and material sciences – into a common network to investigate integrative production theories. It integrates a highly complex and heterogeneous network of 19 university institutes, 7 associated institutes and further non-university research institutions (e.g. from the Fraunhofer Society) as well as different industrial advisors. Because of this, the organizational structure of the cluster contains a cross sectional research field to cope with the challenge of interdisciplinarity in the context of production engineering. With reference to the introduced cluster, contemporary tendencies such as the integration of cognitive elements or the contribution of information technologies to production engineering extend the scope of classical mechanical engineering. Furthermore, the challenge can be characterized by external requirements to interdisciplinary research following the strategies of the German Research Foundation, the German Science Council or the European Union.

According to that, after an overview of actual challenges in interdisciplinary research and network management, the cross sectional approach will be outlined. Moreover, the development of a model for the management of Cross Sectional Processes and the respective methodological approach are discussed. The paper concludes with preliminary findings in cluster-specific interdisciplinary research and recommendations for successful cooperations in the context of the Cluster of Excellence and its learning and knowledge management activities. Further possible research questions in the scope of Cross Sectional Processes will be introduced in a final outlook of the paper.

2 Interdisciplinary Network Management as a Contemporary Challenge in Research Environments

Processes of cross linking and networking reveal chances as well as challenges for involved organizations and networks such as a production engineering oriented Cluster of Excellence. Thus interdisciplinary work depicts a research field exploring phenomena like an augmenting complexity through heterogeneous partners, a growing application of hybrid methodologies or an augmenting dynamic of innovation cycles [Bry09]. Because of this the question of managing interdisciplinary cooperation needs to be further discussed [Öbe11]. Primarily, two conditions have to be fulfilled to guarantee network coordination [Sie06]: On the one hand, the condition of effectiveness demands a higher performance of networks than in other forms of coordination like market or hierarchy. Concerning research networks, the output through cooperation is supposed to be higher than in conventional forms of non-integrative research. On the other hand, the condition of efficiency aims at the satisfaction of all actors. In the context of research networks this means that the benefit of cooperation has to be greater than communication and cooperation costs to be executed by each actor [Sie06].

For the development of a structure and organization of Clusters of Excellence and adequate Cross Sectional Processes the following aspects have to be considered in order to ensure the high quality of the cluster output:

- "One of the main attractions of interdisciplinary research is that it allows researchers freedom from disciplinary constraints" [RNS11]. But the heterogeneity of actors can lead to structural, cognitive and cultural challenges in coordination and cooperation, because diverse disciplines (e.g. production and material engineering, informatics as well as business sciences) are integrated in a network applying different or partly shared methodologies, theories and technical terms [RNS11]. This gives space to new scientific possibilities as well as to new scientific challenges regarding communication (like the lack of a common language) and cooperation among single disciplines [RSLK04, Sau05]. Hence, the cultural differences within the cluster afford chances as well as risks concerning the performance of the entire cluster.

- Especially project oriented networks distinguished by a limited project period are characterized by a high staff turnover [Syd10]. Because of this, an on-going fluctuation of actors may have chances and risks regarding the coherence of the network which may lead to a delay in the process of network development.
- The highly-complex research processes in networks such as a Cluster of Excellence demand the identification and continuous adaption of knowledge interfaces in terms of human, organizational and technological aspects. Following Sydow (2010) this implicates that methods of evaluation and reflection have to be included into a network management approach. Thus, a model for the management of Cross Sectional Processes has to contain elements of evaluation and reflection.

With reference to the challenges of interdisciplinary management in scientific oriented networks, the Cross Sectional Processes comprise two approaches:

a) The provision of special services cross-linking the cluster actors, so called "Network Services" [SZ09, BMzK09, JWR+10] (e.g. organizational measures like colloquia for employees or digital knowledge management tools) aims at promoting the cluster-internal cooperation and the scientific output.
b) Cross Sectional Processes also comprise an own scientific layer in the Cluster of Excellence "Integrative Production Technology for High-Wage Countries" researching on the continuous optimization of cross linking interdisciplinary scientific actors. The results of a performance measurement system (cf. Sect. 3.1) are used for a further development of the entire cluster strategy and single "Network Services" (ibid.).

A strong dependency exists between both approaches. On the one hand, results of the scientific layer continuously influence a modification of the "Network Services" (ibid.). On the other hand, new research questions arise with the implementation of different "Network Services" (ibid.).

3 Cross Sectional Processes and Methodology Used

With reference to contemporary challenges in interdisciplinary network management, further research on an overall model for the management of Cross Sectional Processes in the context of scientific research networks like the Cluster of Excellence "Integrative Production Technology for High-Wage Countries" is necessary. Although e.g. Defila et al. [DSDG06] define in their work relevant steps to manage interdisciplinary projects, further specific aspects in the context of highly-complex interdisciplinary research networks, like different hierarchical levels or staff-turnover, have to be considered in this research field. These aspects directly influence the model for the management of Cross Sectional Processes which simultaneously includes the levels: human, organization and technology.

Hence, to face this challenge and to answer the research question (cf. Sect. 1), Cross Sectional Processes are developing a model to point out specific measures for

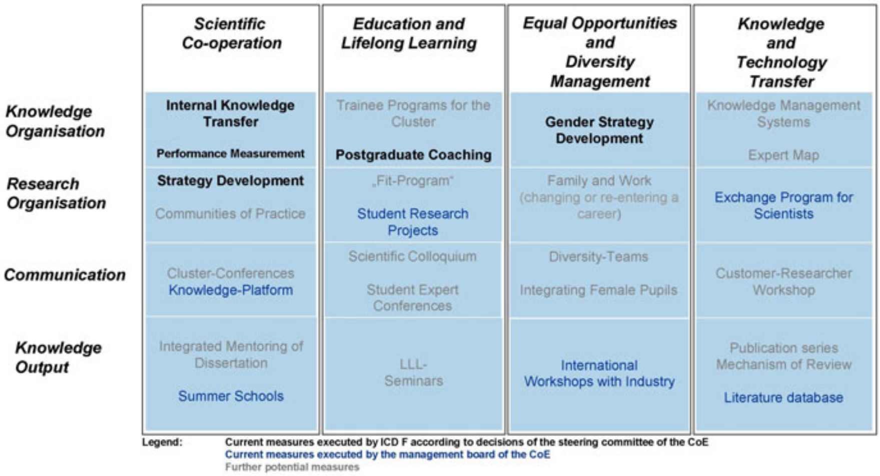

Fig. 1 Toolbox of Cross Sectional Measures

a promotion of interdisciplinary cooperation and cluster development at respective phases of network development. Ahrens et al. classify phases of network development in initial phase, stable phase and steady phase [AFF+04]. According to this, a toolbox of cross sectional measures for different levels of cluster-internal scientific cooperation (such as Knowledge Organisation, Research Organisation, Communication, and Knowledge Output) is implemented.

The field-tested measures originating from the Federal Ministry of Education and Research (BMBF)-project SENEKA were adapted to the needs of a production engineering cluster. On basis of the experience in cross linking heterogeneous actors, first measures of the toolbox were advised to be implemented in the cluster in accordance with the steering committee and the cluster management board (cf. Fig. 1).

Regarding the actually implemented cross sectional measures in Fig. 1 the focus is set on the segment of Scientific Co-operation underlining a major challenge of cluster coordination (cf. Sect. 2). In order to examine these measures, a set of quantitative and qualitative methodologies is crucial to manage the highly cross linked scientific cooperations. Therefore, three different methodologies (used to generate three different data sets) are explained in the following lines.

3.1 Performance Measurement

The implementation of a research-cluster-specific Balanced-Scorecard-Approach – as a first methodology used – refers to the model of Kaplan and Norton (1992) and constitutes a "performance measurement system" originally designed as a communication, information and learning system for enterprises [KN92]. The approach is re-designed to the needs of scientific research clusters and apart from an implementation in the production engineering cluster it is used in the Cluster of Excellence "Tailor-Made Fuels from Biomass" at RWTH Aachen University [WVI10]. The approach is characterized by the measurement and comparison of performance indicators on different hierarchical layers (e.g. the layer of sub-project leaders or the layer of the management board) and bases on a survey among all cluster actors to evaluate for instance the quality of scientific cooperation or the scientific output. With reference to the initial Balanced Scorecard, the cluster-specific tool contains four adapted perspectives which strictly refer to the overall vision of the cluster – the solution of the Polylemma of Production Technology:

1st The Internal Perspective/Research Cooperation
2nd The Learning and Development Perspective
3rd The Output/Customer Perspective
4th The Financial Perspective.

This enables the measurement of scientific oriented performance indicators, e.g. the generation of excellent publications or the education of excellent researchers in production engineering. Concerning this, the development of the different subtargets can be measured yearly by means of cluster-internal evaluations. Through yearly iterations, data is collected and analysed in order to work out recommendations together with the management board of the cluster. Thus, the performance of the cluster can be reflected to enable a steering of the entire network. Furthermore, this supports the adaption of cluster strategies through the consideration of relevant external influences (single-loop-learning) and the adaption of fundamental management ideologies and values (double-loop-learning) [Bra10, KN97].

Until today, three Balanced-Scorecard-based evaluations were implemented in the Cluster of Excellence with 117 respondents in average. In contrast to Kaplan and Norton, who do not suggest a certain method to generate and to collect key performance indicators, a standardized survey has been developed by the Cross Sectional Processes together with the management board of the cluster. By this means performance indicators of a scientific network become measurable (e.g. the quality of cooperation). Analyzed by use of descriptive statistics, the performance indicators become measurable and comparable through arithmetic averages or median.

3.2 Direct Evaluations

In addition to the yearly Balanced-Scorecard-based evaluation (which constitutes an indirect form of evaluation), cluster-specific meetings and events (like colloquia for employees) are evaluated with additional surveys by the participants subsequently to each event. This second methodology is implemented to gain further feedback of the use of single cross sectional measures at a respective phase of network development.

3.3 Structured Interviews

In contrast to the performance measurement approach and direct evaluations, a qualitative method of generating data is given by the method of structured interviews with participants of the cluster. Hence, 24 interviews (representing all sub-projects of the Cluster of Excellence) were carried out on different hierarchical levels by representatives of the Cross Sectional Processes – including professors, leading researchers, members of the management board and sub-project leaders – to enable a broad review of already introduced cross sectional measures.

3.4 Overall Analysis and Triangulation

With the approach of the Grounded Theory [GS08, SC96, Str08], which depicts a widespread method for the development of organizational management theories and models, a data based theory can be developed to illustrate the complex social reality by data. Because of this, a data triangulation of the three introduced methodologies is necessary. During the process of triangulation, hypotheses are formulated defining cross sectional measures that aim at ensuring the high quality of scientific output at a certain phase of network development (initial phase, stable phase and steady phase) [AFF+04].

4 Discussion of Preliminary Results

Cross Sectional Processes in the Cluster of Excellence "Integrative Production Technology for High-Wage Countries" at RWTH Aachen University provide cluster-specific means of learning and knowledge management to support the high quality of scientific output in the cluster. The following preliminary results of the yearly performance measurement, the direct evaluations and the structured interviews outlined several aspects that have to be considered:

- Through the triangulated data analysis the importance of more intensive cross sectional activities on the level of the four core Integrated Cluster Domains (ICDs) was underlined for a successful cluster development. Following the results of the data, especially in the initial phase of the cluster, the work on the level of the single ICDs has to be initialized and supported e.g. through regular ICD-meetings in order to foster the exchange of sub-project leaders and researchers.
- As a reaction to the results of the Balanced-Scorecard-based evaluations from 2008 to 2010, an optimization of interlinking the different ICDs was advised. This was realized through so called 'demonstrators' by the cluster management board. Demonstrators can be described as highly cross linked sub-projects integrating researchers from different ICDs and/or single partners from industry to

foster cross sectional scientific exchange on the one hand and the integration of applied research on the other hand.

- Further figures from the analysed data made obvious that the personal benefit for researchers participating in meetings decreases with an augmenting number of participants in meetings. Considering that, a stronger implementation of regular meetings with smaller groups of participants (e.g. sub-projects and ICDs) has to be favoured to foster the interdisciplinary cooperation instead of too many meetings on the level of a general assembly.
- Especially following the interview statements of project leaders, a new definition of the role of project leaders as knowledge agents has to be aspired, because it is mainly this group that integrates and transfers project-specific knowledge into the ICD and other parts of the Cluster of Excellence.
- Moreover, with regard to other forms of cross linking actors within the cluster, the data analyses of the Cross Sectional Processes revealed that although there is a high awareness among the researchers about the need of digital tools to network different actors, the current networking devices are not used regularly (e.g. the common data platform). Possible solutions thus comprise e.g. a stronger integration of the data platform into the official cluster homepage, the integration of a semantic web into the data platform to connect contents with single scientists and projects or the integration of calendar functions for common appointments and seminars with regard to advanced training activities.
- In general a more interactive form of digital networking is desired following the data analyses and seems to be promising considering an increase of interdisciplinary cooperation as well as the scientific output.
- As an overall cross sectional measure, the regular implementation of the Balanced-Scorecard-Approach has been shown as important to control the research paths of the Cluster of Excellence in all development phases of the network by means of a comparable common data set. The performance measurement tool enables a reflection and redesign of already introduced operational activities on the one hand and the adjustment of long-term management strategies on the other hand. Referring to the process of critical examining long-term strategies, Kaplan and Norton speak of "Double-Loop-Learning" [KN97].
- With regard to the production engineering focus of the cluster, the Balanced-Scorecard-Approach thus enables the regular measurement of the status quo to support the high quality of the scientific output or the training of excellent researchers. Although the process of double-loop-learning [Bra10, KN97] has started on the level of the management board, a further adaptation of the tool to actual needs of the production engineering oriented network is aspired sharpening the outcome of the measurement approach for all groups of actors. In addition to that, a stronger bottom-up approach during the definition of cluster-specific key performance indicators (for instance by means of a kick-off workshop) is recommendable to augment the willingness of all actors of the cluster to participate in the evaluations.

The preliminary results of the Cross Sectional Processes underlined the importance of a holistic view – integrating human, organizational and technological levels with regard to learning and knowledge management activities. Referring to the condition of effectiveness and the condition of efficiency (cf. Sect. 2) this suggests for the human level that e.g. a cluster-specific advanced training for project leaders has to be designed. On the organizational level, e.g. formats like 'demonstrators' strengthen the exchange beyond scientific disciplines. In doing so, a value added for the scientific working process is generated and synergies among scientists are supported. Concerning the technological level of learning and knowledge management, methods and concepts like knowledge retrieval are increasingly important to support a digital form of interlinking actors and to reduce time for searching information. Through the implementation of regular cluster-specific evaluations and performance measurement activities, not only tailor-made measures can be adapted continuously but also a reflection of the entire structure and organization of the Cluster of Excellence becomes possible.

5 Outlook and Further Research Questions

Due to the fact that the empirical study in the context of the model generation included the evaluation of already implemented measures of learning and knowledge management, the project results can be used for two targets. On the one hand they constitute the empirical pillar of the ASPO (a model of use for **A**rrangements and Instruments of the Cross **S**ectional **P**rocesses in the knowledge-intensive **O**rganization Cluster of Excellence), besides the theoretical pillar of interdisciplinary network management. On the other hand, the results are used for a strategic re-alignment of the Cross Sectional Processes concerning a second funding period of the Cluster of Excellence "Integrative Production Technology for High-Wage Countries". Referring to the latter, cross sectional research areas like performance measurement (e.g. by means of the Balanced-Scorecard-Approach as well as intellectual capital reporting) and diversity management (in terms of culture, age and gender) will be extended. The new cross sectional research area of interdisciplinary innovation management will be initiated to raise the researchers' capability of learning and applying interdisciplinary methodologies and theories. Moreover, the area of knowledge and cooperation engineering will be integrated underlining the importance of cross sectional aspects like modelling and managing interdisciplinary knowledge flows.

During the next months ASPO will deliver further answers to the question:

> Which Cross Sectional Processes are crucial to foster the development of the knowledge-intensive network into phases of higher scientific productivity ensuring a high quality of the output?

Since models of scientific network development [AFF+04, Mor96, DSDG06] have to cope with a highly complex and dynamic environment, the ASPO aims at creating a concept of cross sectional management providing the right cross sectional measure for a certain phase of network development. Dynamic in terms of a high fluctuation among the employed scientists in the cluster thus depicts a major challenge for learning and knowledge management. Due to the fact that the cluster is mainly embedded in a German university environment, which is characterized by relative instable and discontinuous working conditions, the number of fixed term contracts is relatively high. Because of this, another research question has to be answered by Cross Sectional Processes in future:

> Which Cross Sectional Measures are exceptionally important to deal with an increased staff turnover in the context of Clusters of Excellence?

A further transfer of cross sectional measures and tools to other forms of scientific oriented clusters and comparable networks is aspired by the Cross Sectional Processes to support scientific oriented interdisciplinary cooperation in future.

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Open Innovation – Kunden als Partner
Wie Hochschulen von Unternehmen lernen können

Jessica Koch, Katharina Schuster, Frank Hees, Sabina Jeschke

Zusammenfassung Die Innovationsstrategie Open Innovation und ihre verschiedenen Methoden kommen in immer mehr Unternehmen zum Einsatz. Für das Hochschulmanagement bieten sich ebenfalls Chancen – insbesondere für das Bologna-Ziel, mehr Hochschulpersonal sowie Studierende bei der Weiterentwicklung des Europäischen Hochschulraums zu integrieren. Im folgenden Artikel wird zunächst das Prinzip Open Innovation beschrieben und auf den aktuellen Forschungsstand, auch im Bereich von KMU, eingegangen. Ausgehend von Unternehmen wird Open Innovation auf den Hochschulsektor übertragen sowie aktuelle Pilotarbeiten im Rahmen des Kompetenz- und Dienstleistungszentrums für das Lehren und Lernen in den Ingenieurwissenschaften TeachING-LearnING.EU vorgestellt. Dabei wird besonderes Augenmerk auf ein zu entwickelndes Controlling-Instrument zur Bewertung der verschiedenen Maßnahmen und zur Steuerung offener Innovationsprozesse gerichtet.

Schlüsselwörter: Open Innovation, Bologna-Prozess, externe Stakeholder, Lead-User, Ideenwettbewerb

1 Einleitung

Die Innovationsstrategie Open Innovation und ihre verschiedenen Methoden kommen in immer mehr Unternehmen zum Einsatz. Für das Hochschulmanagement bieten sich ebenfalls Chancen – insbesondere für das Bologna-Ziel, mehr Hochschulpersonal sowie Studierende bei der Weiterentwicklung des Europäischen Hochschulraums zu integrieren.

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In der Wirtschaft wird Open Innovation insbesondere in großen Unternehmen bereits erfolgreich eingesetzt. Auch kleine und mittlere Unternehmen nutzen, wenn auch bisher vereinzelt, das offene Innovationsmanagement zur Generierung von Ideen und zur Schaffung nachfrageorientierter Produkte. Die Übertagung des Open Innovation-Ansatzes auf andere Bereiche liefert neue Erkenntnisse für die Forschungsrichtung des Wissenschaftsmanagements. Im folgenden Artikel wird zunächst das Prinzip Open Innovation beschrieben und auf den aktuellen Forschungsstand, auch im Bereich von KMU, eingegangen. Ausgehend von Unternehmen wird Open Innovation auf den Hochschulsektor übertragen sowie aktuelle Pilotarbeiten im Rahmen des Kompetenz- und Dienstleistungszentrums für das Lehren und Lernen in den Ingenieurwissenschaften TeachING-LearnING.EU vorgestellt. Dabei wird besonderes Augenmerk auf ein zu entwickelndes Controlling-Instrument zur Bewertung der verschiedenen Maßnahmen und zur Steuerung offener Innovationsprozesse gerichtet.

2 Open Innovation in Wirtschaft und Wissenschaft

Innovationen gelten heutzutage als Schlüsselfaktor für wirtschaftlichen Erfolg und die Wettbewerbsfähigkeit von Unternehmen. Durch den rapide voranschreitenden technischen Wandel insbesondere im Bereich der Informationstechnologien, kürzere Produktlebenszyklen, globalen Wettbewerb und heterogenes Nachfrageverhalten von Konsumenten sind die Rahmenbedingungen für das unternehmerische Innovationsmanagement äußerst vielschichtig und komplex. Vor allem große Unternehmen nutzen neben dem seit Jahrzehnten gewachsenden internen Wissen die Kenntnisse und Ideen ihrer Umwelt. Die Öffnung und der damit verbundene **Einbezug externer Akteure in den gesamten Innovationsprozess** haben den Begriff **Open Innovation** geprägt (vgl. z. B. [Che03]). Dabei können **neben den Kunden und Lieferanten eines Unternehmens auch externe Forschungsstellen und Universitäten** etc. zur gemeinsamen Generierung von Ideen herangezogen werden.

Für Unternehmen, aber auch öffentlich Einrichtungen, ergeben sich durch den Einbezug externer Akteure verschiedene Vorteile. **Der Innovationsprozess wird generell beschleunigt**, da sich insgesamt mehr Personen an ihm beteiligen, was wiederum zu einem größeren Lösungsraum führt. Durch die direkte Einbeziehung der Nutzer in den Prozess entfallen die oft zeitaufwändigen Marktforschungsmethoden [Bre08], **ebenso wird die Marktakzeptanz der Produkte gesteigert**. Dies resultiert aus der Berücksichtigung der Bedürfnis- und Lösungsinformationen zu einem – in Relation zur gesamten Entwicklungszeit betrachtet – sehr frühen Zeitpunkt. Dadurch steigt häufig auch die Bereitschaft der Endverbraucher, für das Produkt einen höheren Preis zu zahlen als für ein vergleichbares Konkurrenzprodukt [FP04].

3 Praxisbeispiel LEGO Mindstorms

Viele Großunternehmen können durch den Einsatz der Open Innovation-Strategie bereits Erfolge verzeichnen: Im Falle von LEGO war die **Entwicklung der Mindstorms Roboter Ende der 1990 Jahre in Kooperation mit einer Forschungsabteilung des Massachusetts Institute of Technology (MIT)** erfolgt – insofern handelte es sich schon um einen offenen Innovationsprozess. Darüber hinaus gelang es jedoch einigen Usern, kurz nach der Markteinführung den Programmierungscode der Mindstorms zu knacken. Nachdem der Code im Internet allen Usern zugänglich gemacht worden war, konnten neue Eigenschaften und Fähigkeiten programmiert werden. Diese waren von LEGO zwar nicht vorgesehen, sie entsprachen jedoch den Bedürfnissen der User. Statt diese zu verklagen, entschied sich LEGO dafür, ihr Wissen und die Bedürfnisinformationen zu nutzen und führte **für die zweite Mindstorms-Generation Workshops mit Usern zur Ideengenerierung** durch [Wil07].

4 Übertragung von Open Innovation auf andere Bereiche

Bei der Übertragung von klassischen Open Innovation-Maßnahmen auf neue Bereiche sind insbesondere deren spezifischen Eigenschaften zu berücksichtigen, die sie von großen Unternehmen abgrenzen. Die hier aufgeführten KMU-spezifischen Eigenschaften weisen eine starke Ähnlichkeit zu den Spezifika von Hochschulen auf und werden im Laufe des Artikels wieder aufgegriffen. Für KMU gilt, dass auf der sozialen Ebene die Vormachtstellung des Geschäftsführers eine ausschlaggebende Rolle spielt. Die Einstellung der Unternehmensführung wirkt sich auf alle zu betrachtenden Faktoren zur Umsetzung von Open Innovation-Maßnahmen aus. Auch **intensive Kundenbeziehungen bieten eine Basis für eine aktive Integration externer Stakeholder**. Die sozialen Beziehungen der Mitarbeiter untereinander und zum Unternehmen gelten in KMU als entscheidend für die Bereitschaft, Veränderungen im Unternehmen vorzunehmen und externes Wissen in den Innovationsprozess einfließen zu lassen. So kann die aufgrund der geringen personellen und finanziellen Ressourcen häufig fehlende Forschungs- und Entwicklungsabteilung durch die externe Ideengenerierung ersetzt werden [Min01]. Laut Walcher [Wal06] können KMU ebenso wie große Unternehmen vom ergänzenden Einsatz von Open Innovation profitieren.

5 Nutzenbewertung von Open Innovation-Maßnahmen

Ein Instrument zur Bewertung einzelner Open Innovation-Maßnahmen, das Organisationen den Nutzen der Maßnahmen verdeutlicht, wird die Überwindung der angesprochenen Barrieren sowie die Entscheidung für ein offenes Innovationsmanagement erleichtern. Ein solches Controlling-Instrument wird derzeit für KMU am Institut für Unternehmenskybernetik (IfU) der RWTH Aachen entwickelt. So wird dazu beigetragen, Open Innovation auch für andere Arten von Organisationen nutz- und handhabbar zu machen.

Ausgehend von den allgemeinen Aufgaben des Innovationscontrollings (vgl. z. B. [Lit05]) muss ein **Open Innovation-Controlling** dabei vor allem folgende Aspekte beinhalten:

- **Informationsversorgung bzw. Gestaltung eines auf den geöffneten Innovationsprozess ausgerichteten Informationssystems.** Dies umfasst insbesondere die Identifikation und Gewinnung externer Informationsquellen sowie die Pflege, Aufbereitung, Verteilung und Nutzung des gewonnenen Wissens.
- **Maßnahmen und Verfahren zur Bewertung der Informationen externer Akteure.** Innovationscontrolling muss hier die Fähigkeit aufweisen, externe Informationen zu verarbeiten bzw. zu assimilieren. Die Mitarbeiter müssen mit Hilfe des Instruments für die Aufnahme, Analyse und Verarbeitung externen Inforationen sensibilisiert werden.
- **Unterstützung bei der Organisation der Innovationsprozesse und -programme.** Dies betrifft z. B. die Ablauforganisation, die Wahl der Open Innovation-Methoden und ihre Implementierung.
- **Berücksichtigung verhaltenswissenschaftlicher Aspekte.** Durch die Kenntnis über die Motive der Akteure, warum sie sich an Open Innovation-Prozessen beteiligen, kann positiver Einfluss auf eine innovationsförderliche Kultur genommen werden. Außerdem wird die Überwindung von Abwehrhaltungen (Not-Invented-Here-Effekt) durch intrinsische oder extrinsische Anreizgestaltung unterstützt.

Geplant ist, dieses Controlling im Forschungsvorhaben „Invoice“ unter Rückgriff auf das bewährte Verfahren der nutzenorientierten Wirtschaftlichkeitsschätzung [Wey00] anzugehen, das sowohl ex ante (als Unterstützung zur Entscheidung für die Einführung von Open Innovation in KMU) als auch innovationsbegleitend (als parallel abrufbares Kontrollinstrument) „harte“ und „weiche“ Faktoren der Open Innovation-Maßnahme messen und auswerten kann. Die klassischen Verfahren der Wirtschaftlichkeitsbewertung (wie bspw. der Return on Investment, ROI) werden hierbei ergänzt, indem auch der Nutzen von Open Innovation-Maßnahmen integriert wird. Um dies gewährleisten zu können, werden erfolgskritische Faktoren identifiziert und analysiert. Deren Kenntnis ist erforderlich, um den gestellten Anforderungen an ein Open Innovation-Controlling gerecht werden zu können. Diese **Teilergebnisse münden in dem sogenannten Return on Open Innovation (ROOI), der zur Effektivitäts- und Effizienzbemessung von Open Innovation herangezogen werden kann**. Das regelkreisbasierte Controlling-Instrument soll die Möglichkeit bieten, Teile der Ausgangsgrößen des Open Innovation direkt oder in modifizierter Form auf den Eingang des Systems zurückzuführen (Rückkopplungseffekt).

6 Neue Chancen für Hochschulen

Die Umsetzung von Open Innovation-Methoden ist je nach Bereich mit unterschiedlichen Rahmenbedingungen sowie Akteursbeziehungen und -bedarfen verknüpft. Gemessen an den Erfolgen von Unternehmen ergibt sich **auch für den Hochschulsektor ein enormes Innovationspotenzial**. Der Bedarf liegt auf der Hand: Laut der europäischen Bildungsminister sind 10 Jahre nach Unterzeichnung der Bologna-Deklaration noch immer Nachbesserungen hinsichtlich Curriculum-Entwicklung, Qualitätssicherung oder Mobilitätsförderung nötig. Sowohl Hochschulpersonal als auch Studierende sollen dabei involviert werden [oHE10]. In Deutschland zeigen aktuelle Initiativen wie der „Qualitätspakt Lehre" von Bund und Ländern oder der „Wettbewerb Exzellente Lehre" des Stifterverbandes, dass im Bereich der Studienbedingungen dringend nachgebessert werden muss. **Innovationen in der Hochschulentwicklung, hervorgebracht von Lehrenden *und* Studierenden** – so könnte ein Szenario für die Zukunft aussehen.

Doch die Übertragung von Open Innovation auf das Hochschulmanagement gestaltet sich keineswegs trivial. **Sind Studierende tatsächlich Kunden der Hochschule?** Sind die Produkte, die entwickelt werden sollen, neue Studienmodelle und Lehrkonzepte? Laut Hees und Isenhardt [HI05] hat Wissenschaft allgemein immer mehrere Kunden – von intermediären Organisationen über Ministerien und Projektträger bis hin zu Studierenden und Bürgern. All diese Kunden haben unterschiedliche Interessen. Auch wenn die Grenze zwischen der Wissenschaft und ihren Kunden nie ganz aufgehoben werden kann, so ist auch die Wissenschaft gefordert, neue Strategien für mehr Innovation in Wirtschaft und Gesellschaft zu entwickeln. Voraussetzung ist ein reifes Verhältnis zu den Kunden, das auf einer Partnerschaft basiert. Dieses Rollenverständnis siedelt sich in der Mitte von zwei Extremen an. Das eine ist die Sicht des Kunden als Abnehmer, der gewissermaßen die Holschuld beim Anbieter hat. Auf der anderen Seite steht die Sicht des Kunden als König, bei dem der Anbieter die Bringschuld hat. Das Verständnis vom Studierenden als Partner wurde auch von den Europäischen Bildungsministern im Rahmen des Bologna-Prozesses geäußert. So heißt es in der Prager Erklärung von 2001: „Ministers stressed that the involvement of universities and other higher education institutions and of students as competent, active and constructive partners in the establishment and shaping of a European Higher Education Area is needed and welcomed (...) Ministers affirmed that students should participate in and influence the organisation and content of education at universities and other higher education institutions." [oHE01] Vor diesem Hintergrund erscheint die Übertragung von Open Innovation auf das Hochschulmanagement berechtigt und sinnvoll.

Im **Kompetenz- und Dienstleistungszentrum TeachING-LearnING.EU**, das sich mit der Qualitätssicherung ingenieurwissenschaftlicher Studiengänge im Zuge des Bologna-Prozesses beschäftigt, werden bereits Methoden eingesetzt, die auf dem Open Innovation-Prinzip beruhen. Das Gemeinschaftsprojekt der RWTH Aachen, der Ruhruniversität Bochum und der Technischen Universität Dortmund hat sich mit dem Programm Open Bologna zum Ziel gesetzt, **gemeinsam mit Leh-**

renden und Studierenden der Hochschulen neue Ideen zur Verbesserung der Studienbedingungen zu entwickeln.

TeachING-LearnING.EU ruft einmal pro Semester einen Ideenwettbewerb aus, eine besonders verbreitete Open Innovation-Methode, die sich laut Hermanns u. a. durch Effizienzsteigerung des Neuproduktinnovationsprozesses auszeichnet [Her09]. Die Themen bewegen sich rund um Qualitätssicherung der Lehre in den Ingenieurwissenschaften im Zuge des Bolognaprozess. Ein wichtiges Bewertungskriterium ist dabei, dass von Seiten der Studierenden qualitativ hochwertige, konstruktive Lösungsvorschläge eingereicht werden. Ein weiterer wichtiger Punkt ist die Umsetzbarkeit der Vorschläge. Je realistischer und praktikabler sie sind, desto höher stehen ihre Chancen, zeitnah umgesetzt zu werden. Durch die Auszeichnung der besten Ideen mit Preisen werden die Teilnehmer durch Leistungsanreize motiviert. Da die Ideenwettbewerbe die Breite der Studierendenschaft als Zielgruppe haben, ist es entscheidend, so viele wie möglich von Ihnen zu erreichen und das Programm Open Bologna bundesweit bekannt zu machen. Instrumente der Öffentlichkeitsarbeit sind beispielsweise das **Internetportal www.teaching-learning.eu**, auf dem wöchentlich die neuesten Meldungen zum Themenkomplex Lehre und Lernen in den Ingenieurwissenschaften präsentiert werden. Das Kompetenzzentrum ist darüber hinaus in sozialen Netzwerken wie *facebook* oder *studivz* vertreten, um die **Studierenden dort abzuholen, wo sie auch ihre Freizeit verbringen** (vgl. hierzu auch [AY10]). Ein eigener Youtube-Channel rundet das Konzept ab. Das Onlineredaktionsteam wird von studentischen Mitarbeitern von TeachING-LearnING.EU geleitet – so wird die Nähe zur Zielgruppe sichergestellt.

Ein weiteres wichtiges Instrument in Open Innovation-Prozessen ist die Lead User-Methode, sie eignet sich besonders zur Entwicklung von Innovationen mit höherem Neuheitsgrad [LMS+02]. **Als Lead User werden Nutzer bezeichnet, die dem Markttrend immer ein Stück voraus sind**, die Produkte „weiterdenken“ und sie nach ihren Wünschen verbessern [Hip05]. Die entsprechenden Akteure müssen zunächst identifiziert werden, anschließend werden sie zu Workshops eingeladen. **In Anlehnung an die Lead User führt TeachING-LearnING.EU Lead Students-Workshops durch**. Hierfür werden Studierenden der Ingenieurwissenschaften identifiziert, die sich in besonderer Weise für außerhochschulisches Engagement und ihr Interesse an Lehrthemen auszeichnen. **In den Workshops werden mit kreativitätsfördernden Methoden innovative Ideen zur Verbesserung der Lehre in den Ingenieurwissenschaften generiert**. Dabei werden sowohl eigene Ideen als auch solche aus den Ideenwettbewerben aufgegriffen. Weiterhin werden prototypische Konzepte entwickelt, die dann von Mitarbeitern von TeachING-LearnING.EU an wichtige hochschulinterne Entscheidungsträger, aber auch in Netzwerke von Lehrenden hineingetragen werden. Die Herausforderung besteht darin, mit Studierenden gemeinsam neue Ideen zu entwickeln, ohne in ein ‚Weniger-einfacher‘-Schema zu verfallen – **Ziel ist die Erhöhung des Niveaus durch effektivere Lehrmethoden**, nicht das „Weichspülen“ von Studiengängen. Die Akzeptanz für von Studierendenseite entwickelte, gut umsetzbare und qualitativ hochwertige Konzepte ist meist sehr hoch. Zum einen bedeutet es für die Lehrenden selbst weniger Aufwand bei der Restrukturierung ihrer Lehrveranstaltungen, zum anderen ist auch von Seiten der breiten Masse von Studierenden die Akzeptanz von studentisch entwickelten Lehr- und Lernkonzepten deutlich höher.

7 Ausblick für das Hochschulmanagement

Für Hochschulen, die generell eine Professionalisierung ihres Managements Infrastruktur anstreben, scheint Open Innovation ein probates Mittel zur Effizienzsteigerung von Innovationsprozessen in der Hochschulentwicklung zu sein. Die begleitende Nutzung des oben beschriebenen Open Innovation-Controlling-Instruments liefert durch die Effektivitäts- und Effizienzbemessung eine Entscheidungsgrundlage für den weiteren Einsatz von Open Innovation-Maßnahmen.

Bei der Übertragung des gesamten Open Innovation Konzepts auf Hochschulen sind insbesondere aktuelle Entwicklungen in KMU von hohem Interesse. Wie auch in KMU die Unterstützung der offenen Innovationsprozesse durch die Chefetage Einfluss auf den Erfolg der Methode hat, so ist es äquivalent **in Hochschulen von Bedeutung, dass neue Maßnahmen die Unterstützung von Fakultäten und Rektoraten finden**. Dies ist insbesondere für die intrinsische Motivation der sich beteiligenden Studierenden wichtig: Nur wenn die Ideen Chancen auf Umsetzung haben, lohnt es sich aus Sicht der Studierenden, sich zu beteiligen – so lautet eine zu überprüfende These. Die Qualität der Kundenbeziehungen, im Falle von Open Bologna also die Beziehungen der Hochschulmitarbeiter zu den Studierenden, beeinflusst den Erfolg der Maßnahmen. **Für Lead Students-Workshops bedeutet dies vor allem, den Studierenden auf Augenhöhe zu begegnen**, sie im Sinne der europäischen Bildungsminister als Partner zu betrachten und ihnen zu verdeutlichen, dass ihre Vorschläge eine Bereicherung für die gesamte Hochschule sein können.

Für die Arbeit von TeachING-LearnING.EU liegt in Zukunft der Fokus darauf, die neu erprobten Open Bologna-Methoden hinsichtlich Effizienz, Qualität der hervorgebrachten Ideen sowie Motivation der beteiligten Akteure zu evaluieren. Dies entspricht dem Punkt ‚Maßnahmen und Verfahren zur Bewertung der Informationen externer Akteure‘ im Modell des oben beschriebenen Open Innovation-Controlling. Die theoretische Untermauerung der Übertragung von Open Innovation auf das Wissenschaftsmanagement inklusive eines Vergleichs von Merkmalen von Großunternehmen und KMU mit denen von Wissenschaftsorganisationen hat ebenfalls hohe Priorität. Die hierdurch neu gewonnenen Erkenntnisse fließen in ein Re-Design des Open Bologna-Programms ein. Alle weiteren Prozesse werden gemäß eines Open Innovation-Controllings organisiert und strukturiert. Die Informationsversorgung bzw. Gestaltung eines auf den geöffneten Innovationsprozess ausgerichteten Informationssystems wird kontinuierlich projektbegleitend optimiert und professionalisiert. Im Bereich ‚Unterstützung bei der Organisation der Innovationsprozesse und -programme‘ wird geprüft werden müssen, ob sich andere Open Innovation-Methoden wie z. B. Toolkits oder Communities für Open Innovation [Her09] für das Hochschulmanagement besser eignen. Bezüglich der verhaltenswissenschaftlichen Aspekte wird die Motivation von Studierenden sowie von anderen Akteuren untersucht, sich am Open Bologna Programm zu beteiligen.

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Introductory Mathematics Computer Course

A Supplementary Course for a Mathematical Bridge Course

Olivier Pfeiffer, Erhard Zorn, Sabina Jeschke

Abstract The majority of freshmen is overcharged in the transition from high school to academic education at the beginning of their studies. The biggest continual problems appear in mathematics. This is based on the high degree of abstraction and on the fact that the mathematical education for non-mathematicians, mainly engineering students, takes place at the beginning of the studies. Thus, deficiencies become apparent at an early stage. In order to facilitate freshmen's transition from high school to the university the Department of Mathematics offers a four-week introductory course to mathematics before the begin of each semester. The course is addressed particularly to freshmen of the engineering and natural sciences and mathematics. Additionally, a so-called mathematics computer course is offered for a part of the participants of the introductory mathematics course. In this two-week course the participants learn how to handle the Linux operating system, the employment of a computer algebra system (Maple) and obtain an introduction to the scientific text processing system LaTeX.

Key words: Mathematics Bridge Course, Computer Algebra System, Engineering Mathematics, LaTeX, Undergraduate Students

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1 Introduction

Mathematical comprehension and proficiency are some of the most important utensils of engineers and natural scientists. Based on the high degree of abstraction of mathematics for most freshmen the biggest problems in transition from high school to university appear in mathematics for non-mathematicians. Additionally, as opposed to high school, success at the university requires self-organized learning to manage the unusually high density of the syllabus: Typically, topics like curve sketching are dealt with for several months at school, but at the university this is only a side note.

At large universities the extreme demands in mathematics are felt especially serious because the individual student easily gets lost. Therefore, students are recommended to discuss problems in teams and to work in teams to prevent this. This may be unfamiliar to students of colleges in the United States with special honor codes. Because working in teams is typical for their future professional life, students have to be trained to team work already at the university.

Many universities are offering "bridge courses" or preparatory courses to bridge the gap between high school and university. At least at German universities, as far as the authors know, these are additional courses and they are intended as a repetition of the mathematics that (should) have been learned at high school [Sch, SS05, CN05]. Some courses are designed to give the freshmen the opportunity to discover their strength and weakness [Bud95]. Additionally, there are courses where students have the opportunity to take the mathematics of the first semester before they enroll at the university [JKPZ09].

2 Mathematics Bridge Course

In order to facilitate the transition from high school to university the Department of Mathematics offers a four-week bridge course before each semester. In this course mathematics on the level of an advanced high school course is repeated. The course consists of a daily two-hour lecture and a two-hour exercise. Before the summer semester regularly 300–400 and before the winter semester 800–1000 freshmen participate in this course (see Fig. 1). Because of financial reasons recitations classes in small groups cannot be offered.

The course repeats the last five years of high school mathematics within four weeks. It starts with elementary topics like numbers and arithmetical operations and end with complex numbers rarely dealt with at high school. The main topics of the course are as follows:

- Numbers and arithmetic operations
- Fractions
- Powers
- Binomial theorem

Fig. 1 Mathematics Bridge Course

- Elementary algebra
- Linear functions and linear maps
- Quadratic functions and quadratic equations
- Roots and radical equations
- Exponential functions
- Logarithm
- Euclidean plane geometry
- Trigonometric functions and trigonometric equations
- Elementary Combinatorics
- Mathematical symbols, formulae and texts
- Elementary logic and mathematical proofs
- Functions and differentiability
- Maxima and minima
- Integral calculus
- Euclidean solid geometry
- Vector calculus
- Systems of linear equations
- Matrices
- Complex numbers.

Only approximately half of the freshmen students in engineering studies participate in the mathematics bridge course. Some reasons are a lack of time, especially for students coming from abroad or moving to Berlin, military service/alternative civilian service or internships that have to be completed before the enrollment. Therefore, the department of mathematics also offers an online bridge course [mata].

Fig. 2 Students working in the Unix Pool

This course has been developed at the Royal Institute of Technology (KTH, Stockholm) and is offered to all freshmen at Swedish universities. This course has been translated to German and it is offered at four large institutes of technology, among them three members of the TU9 German Institutes of Technology e.V., an incorporated society of the nine largest universities focusing on engineering and technology [tu9].

3 The Mathematics Computer Course

In addition to the mathematics bridge course, we offer a so-called mathematics computer course. This is a two-week course, offered to a part of the participants of the introductory mathematics course. Two participants each work together on one computer in the largest computer pool of the university, the Unix Pool (see Fig. 2). The mathematics bridge course (lecture and exercise) is held from 9 a.m. until 1 p.m. During this four-week course the participants of the mathematics computer course are working from 1 p.m. until 6 p.m. in the computer pool. For most of the students this is the first time they are working more than 8 hours a day, but this is a good opportunity to familiarize with academic life.

In this two-week course the participants learn how to handle the Linux operating system [wik], the employment of the computer algebra system Maple [Hec03, map11, BCD+11] and obtain an introduction to the scientific text processing system LaTeX [Knu86a, Knu86b, Lam94, MG05]. Mathematics as a universal tool for

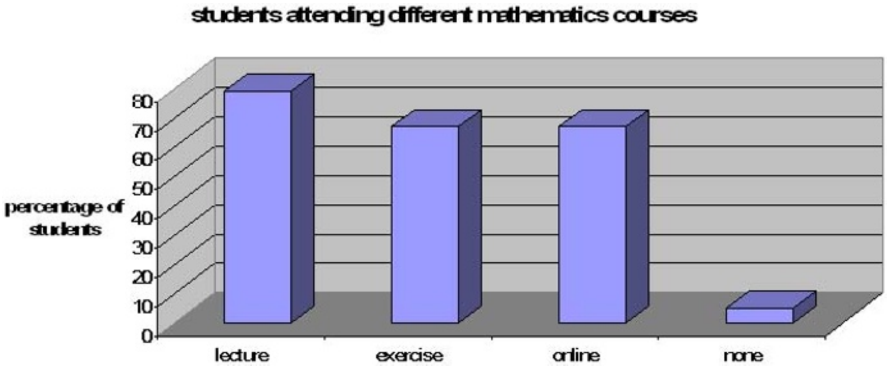

Fig. 3 Percentage of students attending different mathematics preparatroy courses (multiple answers permitted)

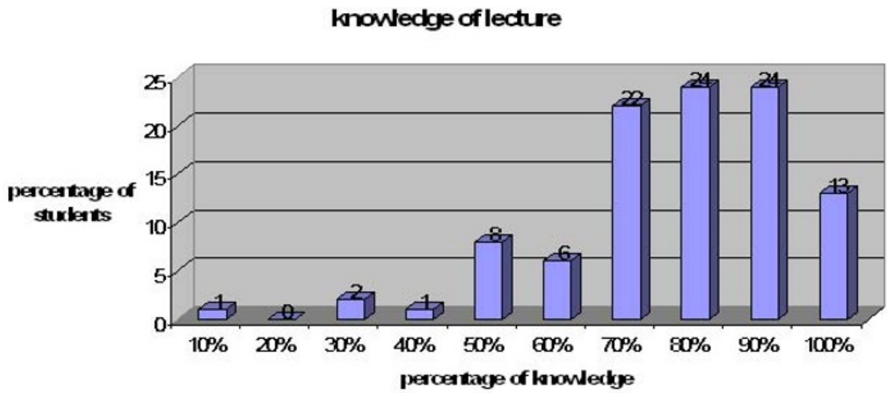

Fig. 4 Knowledge of the topics of the mathematical bridge course (esitmated by students)

users is the connecting component. In the course exercises of the introductory mathematics course are addressed. A problem from the engineer's everyday life is to be solved as final assignment, to which all knowledge obtained from the course has to be used.

The mathematics computer course is offered since 2005 with up to 200 participants before the summer semester and 400 participants before the winter semester. Most of the participants of the mathematics computer course attend several preparatory mathematics courses (see Fig. 3). 35 % of the participants are female, 65 % are male. This is an interesting fact because most of them are engineering students and there are only approximately 25 % female students in these fields. It has been supposed that many male students cannot attend the preparatory courses because of the military service/alternative civil service. Since summer 2011 in Germany the military or alternative service is not obligatory any more, but the female/male ratio of the participants did not change. The reasons are not obvious and have to be investigated in the future.

The main reasons for the freshmen to participate in the mathematics computer course are as follows:

- I want to repeat more mathematics (31 %).
- I want to learn new topics useful for university (24 %).
- My high school diploma dates back some time (23 %).
- I doubt my mathematical skills (10 %).
- This course is known to be helpful (9 %).

Many students estimate their knowledge of the topics of the mathematic bridge course very high (see Fig. 4). Therefore, we assume that participants of the preparatory mathematics courses are eager to learn and repeat as much as they can before the regular courses start.

In several mathematics courses the students are working in the computer pool of the Department of Mathematics which is using the Linux operating system. Therefore, a short introduction into Linux is integrated into the mathematics computer course. Additionally, many students are getting interested in the free operating system Linux during the course.

In the course we are using the computer algebra system (Maple) instead of standard numerical software (e.g. MATLAB [matc]) even if the students will learn to solve engineering problems with numerical software packages in their future academic/professional career. However, at this early stage of their academic education we are emphasizing the mathematical comprehension which can be supported in an ideal way by a computer algebra system instead of numerical software.

We decided to use the commercial computer algebra system Maple instead of an open source software like Maxima [max]. Maple has a very convenient graphical interface (see Fig. 5) and offers the possibility to create interactive worksheets. This gives the possibility to concentrate on mathematics instead of programming. Last but not least, we prefer Maple instead of the other leading commercial computer algebra system Mathematica [matb] for reasons of price policy. Even though we are using commercial software, we recommend to install open source software like Maxima.

For mathematicians, natural scientists and engineers LaTeX is the most used scientific text processing system, especially for technical documents, Bachelor, Master or PhD theses full of mathematical formula. Therefore, we integrated into the course a short introduction to LaTeX. Generally, this is the first time students come into contact with a non-visual oriented text processing system. For most participants the power of LaTeX is amazing and they are eager to learn more about the system.

The mathematics computer course benefits from the freshmen's interest in the computer employment and connects it with the imparting and above all independent exercise of mathematics. Pupils are used to (playful) handling of the computer indeed and also use it as a source of information and for communication. However, the employment as a tool for research and teachings is unfamiliar. Therefore, an emphasis of the course lies in conveying the employment of the computer as a tool for research.

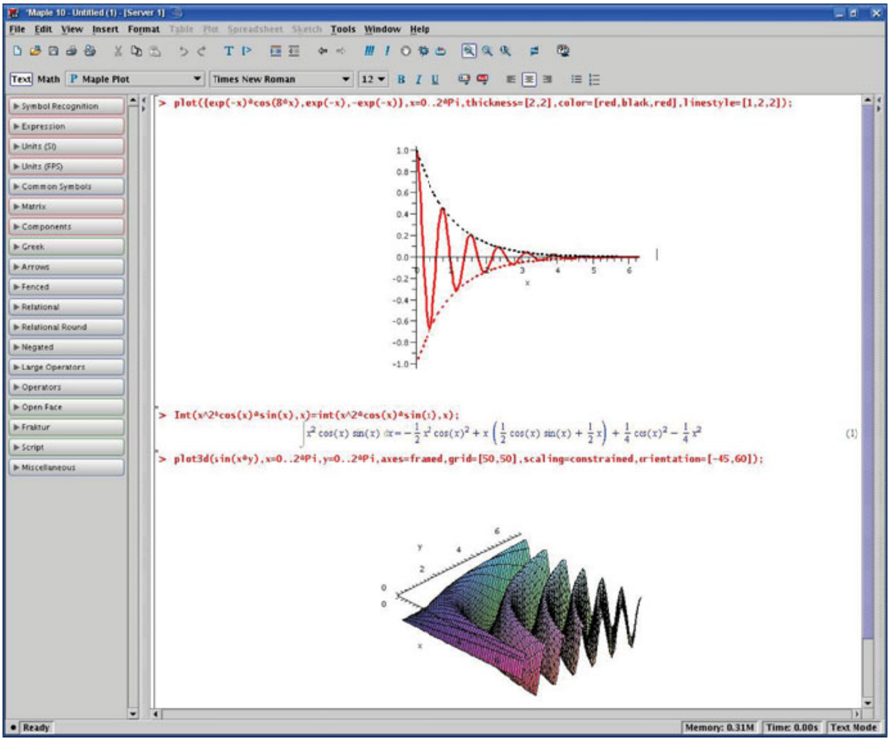

Fig. 5 Screenshot of graphical interface of Maple

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Dipl-Ing Rest in Peace?

The Implementation of the Bologna Process in Germany's Engineering Education

Katharina Schuster, Frank Hees, Sabina Jeschke

Abstract More than ten years after the signing of the Bologna Declaration, the European Higher Education Area has been launched on March 12 2010. Many of the original objectives have made a lot of progress, such as increasing the mobility amongst students in Europe in order to foster intercultural competencies and preparing the graduates for a global job market. In engineering though, the number of students who study abroad is still pretty low. Other aspects like comparable degrees or courses still need further development throughout all fields of study. After a short presentation about the background of the Bologna Process, the following article describes the implementation in Germany's engineering education so far. It also presents different opinions of various stakeholders. Further research questions are being discussed at the end of the paper. The role of the students is paid special attention to throughout the whole text. The article is based on qualitative documentary research.

Key words: Bologna Process, Engineering Education

1 Introduction

More than ten years after signing the Bologna Declaration, the German higher education system has changed a lot. In the past, apart from doctoral studies German universities only provided study courses leading to degrees which resemble a combination of bachelor and master. Those are the *Diplom* (mostly for natural and engineering sciences), the *Magister* (mostly for the humanities) and the *Staatsexamen* for future teachers. The Bologna Declaration fostered the change to a system with two cycles throughout Europe, undergraduate and graduate. Because the bachelor

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usually lasts for three years and the master for two years, the system is also referred to as the 3 + 2 model. Although by now many universities of technology have implemented bachelor and master degrees, it is still difficult to let go of the former degree 'Diplom-Ingenieur', which is comparable to the Professional Master of Engineering at the University of Melbourne and implies excellent engineering qualities. With many years of tradition in engineering, e.g. in the automotive industry or in steel production, graduates from German universities were a popular export. Their academic title 'Dipl.-Ing.' stood for a solid engineering education combined with technical expertise and functioned as a door opener for attractive positions. According to the current situation, since many universities only offer bachelor and master degrees, the title 'Dipl.-Ing.' will slowly disappear from the academic landscape in the future. From the beginning of the process worries have been growing that the German engineering education and therefore the reputation of German engineers could be afflicted by the new system. By losing the title 'Dipl.-Ing', German engineers risk to lose their seal of quality, their uniqueness and their distinguishing characteristics. Even though the discourse about the title 'Dipl.-Ing.' is only a small part of the whole implementation of the Bologna Process, it symbolizes the problems which accompanied the reform in German engineering education. Especially in the light of Australian Universities changing the current system from a traditional 4 year engineering bachelor degree to a 3 + 2 model, the following review of Germany's implementation of the european higher education reform will be of interest also for the Australian audience.

2 Illness or Cure for Europe's Higher Education? The Bologna Declaration

In 1999, 29 European countries signed the Bologna Declaration. This act can be considered the beginning of the biggest higher education reform Europe had ever seen. With the goal to establish a European Higher Education Area the countries committed themselves to follow-up complementary higher education reforms in order to achieve academic compatibility between the different nations.

The main objectives written down in the declaration are

1. Adoption of a system of easily readable and comparable degrees
2. Promotion of European citizens employability
3. Adoption of a system based on two cycles, undergraduate and graduate
4. Establishment of a system of credits, also for the
5. Promotion of mobility
6. Promotion of European co-operation in quality assurance
7. Promotion of European dimensions in higher education [oE99].

The debates in Bologna were accompanied by the founding of the Bologna Follow-up Group (BFUG) in order to evaluate and push the follow-up work of the Bologna Declaration. Signatory countries were supposed to start legislative reforms or governmental action within the higher education systems. Individual universities, higher education committees and related associations were due to analyze and discuss the consequences in their respective countries, although the independence, the autonomy and the individuality of universities were always to be preserved.

The ministers of the 29 European countries explicitly set themselves a deadline: The European space for higher education should be completed in 2010. Since 1999 the ministers of higher education have met every two years in order to move on with the implementation. Today the Process has 47 members who launched the European Higher Education Area on 12 March 2010 by signing the Budapest-Vienna Declaration.

Under point 6, the declaration says:

> Recent protests in some countries [. . .] have reminded us that some of the Bologna aims and reforms have not been properly implemented and explained. We acknowledge and will listen to the critical voices raised among staff and students. We note that adjustments and further work, involving staff and students, are necessary at European, national, and especially institutional levels to achieve the European Higher Education Area as we envisage it. [oHE10].

This statement alludes to the fact, that the implementation of the process was accompanied by problems. At least in Germany, different voices demanded a reform of the reform [Fri10, Dre10a, oT10].

3 Implementation in Germany's Engineering Education

The German Bologna Group consists of different governmental and non-governmental representatives, with the German rectors' conference probably being one of the most cited. Another influential group is the conference of the ministers of higher education of the German federal states, the Kultusministerkonferenz (KMK). This group is the most powerful legislative body on a national level because regarding to the German federal system, all higher education issues fall into jurisdiction of the federal states. The fact that due to the federal system it was not possible to develop one national Bologna strategy surely was one of the main reasons that the reform was progressing slowly. The only way to have a national impact on higher education issues is the Hochschulrahmengesetz (HRG, Framework law on universities and colleges). According to the amendment of the HRG in 1998, German higher education institutions already then had the possibility to award degrees which were comparable to bachelor or master degrees. The number of years which had to be studied for a bachelor degree was at least 3, but no more than 4. The study time for a master degree had to be at least one year but no more than two years long. Alesi et al. [Aea05] found that 'on half-time' of the reform there was no consistent logic of the systems of two cycles. The model of $3+2$ years was in fact the basic structure, but still several variations of that model existed. In 2003 the Kultusministerkonferenz in Germany enacted that all bachelor and master degree programs had to be accredited and all bachelor degree programs had to last between 6 and 8 semesters [Kul03]. The decision of the duration of a bachelor study program shows, that in this case the national framework of the HRG was also accepted by the representatives of the federal states.

The subjects of engineering and economics were considered as precursors regarding the implementation of a new system which provides two academic degrees which both qualify the graduates for a professional life, the bachelor and the master [Aea05]. Nevertheless, during the implementation of the new system the loss of the generally accepted degree of the Diplom-Ingenieur had been an issue all the time. This ambivalence with the quick implementation of new degree programs on the one hand and the commitment to the old degree on the other hand has been typical for the implementation of the Bologna Process in Germany. A possible solution is that universities would be allowed to award two titles for a master degree program – the master of science and the Diplom-Ingenieur. The TU 9, a network of the leading Institutes of Technology in Germany, demands this right from the federal states – however it is not that easy to implement juridically. Similar circumstances were only found in subjects like medicine, law or teaching degrees. But since these subjects were more or less excluded from the reform in the first place, like in many other countries as well, such as Norway, Austria or Hungary [Aea05], the situation was not as ambivalent as in engineering. Many of the university staff in engineering had problems with or arguments against the shift towards a bachelor-master-system. [Aea05] showed that university rectors and employers in general had a more optimistic estimation of the higher education reform than students and staff. Being half way there, the general mood was considered as careful optimistic. By now TU9 switched almost all degree programs to the $3 + 2$ model.

A possible key figure in order to measure how students cope with the new system is the drop out rate. A new study from the Higher Education Information System (HIS) analyzed the drop out rates of different subject groups and the related motifs at 54 universities in Germany. Of all the students who enrolled in engineering sciences between 1999 and 2001, 25 % left university without a degree. Since the measurement started with the enrollers of 1992, this number has stayed on a relatively high level, same as for mathematics and linguistics, cultural sciences and sport sciences (see Fig. 1). What we can also observe is that for subjects like law, economics and social sciences or in agricultural science, forestry and nutrition sciences, the drop out rate has decreased throughout the years. Beside the results listed in Fig. 1 the study also revealed that in Mechanical Engineering the drop-out rate of all enrollers between 1999 and 2001 was 34 % and in Electrical Engineering 33 % [Heu09]. Especially in the context of the global lack of competent professional engineers, this number seems alarming.

If we look at the reasons why engineering students decide to quit, the study illustrates the changes of the motives throughout the years (see Fig. 2).

Counting problems of pressure to perform and failure of exams together, almost 40 % give excessive demands as the main reason for dropping out. By now only 8 % say that they quit because of financial reasons, whereas in 2000 almost one fourth of engineering drop outs claimed that as a reason. Failure in exams used to be the least given reason for dropping out, whereas now it's at 14 %. Heublein et

Data given in %

	first-year students 1992 - 1994 (graduates 1999)	first-year students 1995 - 1997 (graduates 2002)	first-year students 1997 - 1999 (graduates 2004)	first-year students 1999 - 2001 (graduates 2006)
linguistics, cultural sciences, sport sciences	33	35	32	27
law, economics, social sciences	30	28	26	19
mathematics, natural sciences	23	26	28	28
medicine, health sciences	8	11	8	5
agricultural sciences, forestry, nutrition sciences	21	29	14	7
engineering	26	30	28	25
art / science of arts	30	26	21	12
teaching degrees	14	12	13	8

HIS Student Drop-out Investigation 2008

Fig. 1 Development of drop-out rates at universities, subject groups [HHS10]

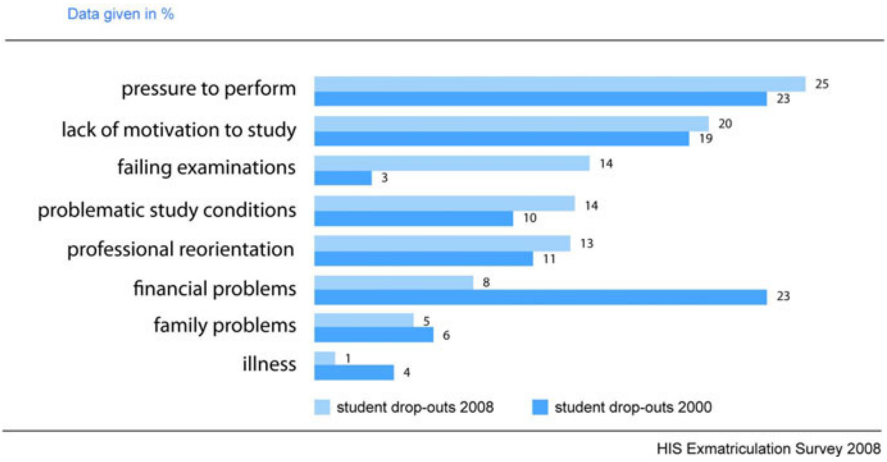

Fig. 2 Reasons for dropping out: Engineering students at universities [HHS10]

al. see that as one indicator of the selective potential of the bachelor studies, where students have to deal with tough exams about the basics in mathematics and natural sciences at a relatively early stage, compared to the old diploma system. Moreover, every seventh drop out gives bad organization and a lack of practical reference as the reason. This could be another indicator for the problems of the implementation of the new system [HHS10].

One major objective of the Bologna Process was to enhance mobility amongst students throughout Europe which is why it is worth looking at this aspect a little closer. Alone within the ERASMUS program, which was started by the European Commission already in 1987, over 2.2 million students have spent a term in a different country in Europe until mid-2010. More than 4000 higher education programs in 33 countries participate in the program [Com10]. ‘Doing ERASMUS’ has become a characteristic of a whole generation of students.

However, a study of the Higher Education Information Center [Heu09] shows that engineering students are the ones with the smallest interest to study in a foreign country. Only 16 % of the engineering students in 2009 studied abroad, whereas in the humanities, medicine (33 %) or languages and culture studies (37 %) it is much more common. Heublein interprets the low mobility rate of engineering students as a result of the faculty culture in Germany's engineering education which amongst other things also forms the mobility behaviour of the students. After financial problems the most reasons why students (not just in engineering) wouldn't enforce studying abroad is a lack of support of the universities, difficult comparability with the demands of the study and time loss in the studies [Heu09]. Unfortunately the study didn't show subject-specific reasons for going or not going abroad.

4 The Voices of the Stakeholders

There are still different voices about the way the Bologna Process was implemented in engineering faculties in Germany. Although he generally supports the Bologna Process and the reform, the Rector of the RWTH Aachen University Prof. Dr.-Ing. Ernst Schmachtenberg openly discussed the amenities of the Dipl.-Ing. in the media. He said that the German degree was a quality product and found it unacceptable to give up the symbolism and the radiance of that brand [Kau10]. The TU9, of which Schmachtenberg is also acting president, from the beginning stressed that the degree for a proper engineer should be the master – not the bachelor [oT10]. The Technische Universität Dresden explicitly holds on to the Diplom degree programs of electrical engineering, informatics and mechatronics because of its worldwide reputation. In Dresden it is not possible to get a bachelor degree in engineering, although some master programs are provided [Dre10b]. The Association of German Engineers (Verein Deutscher Ingenieure, VDI) claims that the bachelor should be a degree which enables the graduate for master studies but also for employment – not a smaller top but a broader basis of engineers should be the goal [VDI10].

The students also participate in the big discourse. Although not comparable to the student's movement in 1968s, the Bologna Process has led to big demonstrations, like in march in Vienna during the conference of the European higher education ministers [Dre10a]. Although they don't want to joggle the original goals of the Bologna Process anymore, students question the acceptance of the bachelor in the industry, especially in small and medium-sized companies. They state that the bachelor doesn't prepare for the working world, that it demands too much learning matter per time, that it doesn't foster mobility and that there are too few offerings of soft skill trainings [Dre10a]. But although it doesn't appear in the media very often, students in Germany have been involved broadly in the implementation of the Bologna Process on an operative level. In the accreditation process students are represented in many bodies and take part in hearings. In internal evaluation processes of universities, the evaluation of lectures by students is a key element [BMB07]. Nevertheless, Bornefeld [Bor] showed at the example of RWTH Aachen University that in mechanical engineering the returns of the students were quite low; student councils may not even have sent the feedback forms back which they had been sent. A wider approach was tried from the ministry of education in Baden-Württemberg, where students got the possibility to e-mail all their problems with the new system directly to the ministry of education [Fri10]. Without judging which one of the processes was better or more successful, the latter obviously had a lower hurdle for students to get involved in the development of the reform because it did not include any obligations or require a great expenditure of time.

5 How to Reanimate the Implementation – Further Steps and Research Questions

Since Heublein contended that the low mobility rate of engineering students results of the faculty culture in Germany's engineering education, future studies need to focus on the one hand the reasons and motifs of German engineering students why the interest of studying abroad is so low – and how to overcome this phenomenon in order to foster mobility. Even if German engineering graduates want to stay on the German job market, the chances are pretty high that they will work in companies which act globally – therefore engineering graduates need intercultural skills. On the other hand institutions which are in charge of fostering the students' mobility, like student advisory services or international offices, need to be analyzed to what extend they provide support and help for the students. Apart from data like the number of enrolments or drop out rates, further key figures which measure the achievement of the Bologna goals, such as the comparability of degrees, the acceptance of degrees etc., need to be collected in order to demonstrate the progress of the reform. Since most of drop-out students in engineering give excessive demands as the main reason for dropping out, the workload and the 'studyability' of degree programs in engineering needs to be investigated as well. In the future the potential of the students to contribute to a successful implementation of the Bologna Process can be made use of in a more effective way than before. Apart from accreditation (meta-perspective) and the evaluation of lectures (micro-perspective) there are plenty of more possibilities to involve the students and create an 'Open Bologna' for everyone who is affected by it. It will be important to involve more students in fields like curriculum improvement or quality assurance and also in a more appealing way than before in order to make use of their innovative potential. They shouldn't just get the ability to share their problems but furthermore their ideas how to improve the implementation of the Bologna Process. In order to make a voluntary engagement in higher education development more attractive for students, they need incentives. Students have to be intrinsically motivated. This is why they need to know how their ideas are handled or if they will be implemented, but they also need some kind of extrinsical motivation like winning a price for the best idea. Since today's students all grew up with digital media, the possibilities of web 2.0 to connect people and to work together on problems without geographical borders need to be exploited. Especially engineering students which can be considered as problem solvers and have great analytical skills might inherit the innovative potential that is needed in order boost further implementation of the Bologna goals. Furthermore, the future alumni of engineering bachelor and master degree programs should be interviewed in order to find out to what extent their studies helped them in their field of work.

In the middle of 2010 the initiative 'Bologna – Future of Learning' from the Mercator Foundation and the VolkswagenStiftung funded degree programs and competence centres for different subjects. In order to tackle the challenges the Bologna Process has set for engineering sciences in Germany, three large and wellknown German Universities of Technology (RWTH Aachen, Technical University Dortmund and the Ruhr-University Bochum) launched the Competence and Service Center for Teaching and Learning in Engineering Sciences TeachING-LearnING.EU (www.teaching-learning.eu). On the service side, the Center organizes communication processes between the different stakeholders of German engineering education; students as well as university staff, employers, political decision makers and associations like the VDI. The Open Bologna program focuses on the involvement of the students. Therefore idea competitions and workshops will be organized. Lecturers of engineering subjects have the opportunity to participate in trainings, where concepts like problem-based learning are presented and connected to technical content. To support the trial of new teaching and learning concepts, flexible funds provide lecturers with the capital needed. On the research side, TeachING-LearnING.EU focuses on the problem of lectures with big audiences (500+) and on the measurement of the achievement of the Bologna goals. Although mainly focussing on the situation in Germany, the Center seeks the professional dialogue with other international associations in the field of engineering education. Especially for countries, which have to deal with similar change processes in the field of higher education, it is indispensable to exchange ideas and learn from each other.

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OpenBologna

A Strategic Instrument for Integrating Students in Curriculum Development

Katharina Schuster, Ursula Bach, Anja Richert, Sabina Jeschke

Abstract In 2010, the Mercator Foundation and VolkswagenStiftung's initiative *Bologna – the Future of Teaching* introduced funding for degree programmes and competence centres for a variety of issues in Germany, following the example of UK Subject Centres.

In order to tackle the challenges in engineering sciences brought about by the Bologna Process, three large German technical universities (RWTH Aachen University, Ruhr-University Bochum and Technical University Dortmund) launched the Competence and Service Centre for Teaching and Learning in Engineering Sciences (known as TeachING-LearnING.EU). Here, students are involved in the improvement of teaching and learning using the strategic instrument of *OpenBologna*. It is based on the concept of *Open Innovation*, developed and used by companies in the business sector to actively integrate customers into new product developments.

This paper illustrates the OpenBologna strategy and its potential benefits for curriculum development. The general aims of the Competence and Service Center TeachING-LearnING.EU and the strategic instrument OpenBologna are presented. A short introduction to Open Innovation describes the foundation on which the new strategy for curriculum development is based. This is followed by some general thoughts about the transfer of Open Innovation to the educational sector and a description of the operational level of OpenBologna. In order to give the reader an impression of the outcome of OpenBologna, the results of the first ideas contest are presented and reflected on in terms of their benefits to curriculum development. The paper concludes with upcoming measures and corresponding research questions.

Key words: Engineering Education, Curriculum Development, Open Innovation, Student Engagement

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1 Introduction: The Aims of the Competence and Service Center TeachING-LearnING.EU and Its Strategic Instrument OpenBologna

When the European Ministers of Higher Education agreed upon the Bologna Declaration in 1999 they had seven main objectives [oHE99]:

1. Adoption of a system of easily readable and comparable degrees
2. Promotion of European citizens' employability
3. Adoption of a system based on two cycles: undergraduate and graduate
4. Establishment of a system of credits
5. Promotion of mobility
6. Promotion of European co-operation in quality assurance
7. Promotion of European dimensions in higher education.

The Bologna Process encouraged a wide range of general improvements to teaching in higher education, particularly during the implementation of Bachelor and Master degrees in Germany. One example is the *Teaching Quality Pact* of the Federal Ministry of Education and Research and the Federal States which commenced in October 2011, funding 111 projects in Germany with 2 billion Euros. Prior to this, the initiative *Bologna – the Future of Teaching* (spearheaded by the Mercator Foundation and VolkswagenStiftung) funded the foundation of three subject centres for engineering, mathematics and medicine. Their goal is to 'facilitate the use of existing and future knowledge and experience to improve teaching quality and to pool it in expert centres, specific disciplines or subject groups' [Mer09].

In June 2010, RWTH Aachen University, Ruhr-University Bochum and Technical University Dortmund launched the initiative for engineering education, TeachING-LearnING.EU, which is developed according to the UK example [Jes09]. Research, service and strategic networking are the key elements of its concept. In its seven research fields, TeachING-LearnING.EU focuses on:

- Best practice monitoring regarding the achievement of the Bologna goals
- Curriculum development
- New teaching and learning concepts
- Competence oriented testing
- Teaching experiments
- Higher education didactics for lectures with large audiences (500+).

The five service fields are:

- Higher education qualification
- Coaching and consulting
- Flexible funds for teaching staff
- Models for doctorate studies
- Following up the work of the Bologna Process in terms of teaching and learning.

Fig. 1 Instruments and stakeholders of TeachING-LearnING.EU

The major goal for strategic networking is to bring together all those involved in engineering education and achieve a broad resonance in German higher education in order to improve engineering education. For each target group a special instrument has been identified to support the communication process (see Fig. 1). Representatives of companies and educational institutions come together twice a year in the Community of Practice in order to meet the Bologna goal of increasing the employability of graduates. An International Advisory Board supports and counsels all actions of TeachING-LearnING.EU from a metaperspective. Special interest groups like the Association of German Engineers (Verein Deutscher Ingenieure, VDI) or the Industrial Labour Union Metal (IG Metall) also facilitate working groups for engineering education which meet regularly with the Competence and Service Centre. The quality of engineering education in Germany is the subject of an annual conference which is actively attended by all of the stakeholders.

Special attention is given to the integration and participation of students in the improvement of teaching and learning. According to the Budapest-Vienna Declaration, student involvement is necessary in order to develop the European Higher Education Area as it was originally envisaged in 1999 [oHE10]. The importance of the participation of students in implementation processes is also stressed by the CDIO initiative, which underpins the relevance of this measure, especially in the field of engineering education [CDI11].

In order to fulfill the rather vague recommendation of the European Ministers of Higher Education of ‘involving students’, it has been the objective of TeachING-

LearnING.EU to establish some key mechanisms and to form an instrumental framework for student involvement. For gathering the students' opinions, the project team found a new and promising method in economic sciences: the Open Innovation concept. Its basic principles are identified and adapted to the demands of the Competence and Service Centre. The main questions of the Open Innovation approach are:

- How can customers be integrated into new product development?
- How can the newly gained knowledge be preserved, used and further developed?
- What is the motivation of the customers to participate in Open Innovation activities?

In 2009 and 2010 many students in Germany protested against the Bologna Process and demanded better study conditions. Points of criticism were, for example, the workload of the Bachelor degree being much higher compared to the former *Diplom* and the former not being accepted by industry. In the context of the student protests during that time, the term *OpenBologna* was adopted for marketing reasons – to attract the students' attention and convince them to support and shape the Bologna Process instead of protesting against it.

The motivation to establish the instrument OpenBologna within the TeachING-LearnING.EU project lies in previous experience with the involvement of students in the implementation of the Bologna Process in Germany's engineering education. So far, student involvement has mostly been restricted to either the meta-level in accreditation processes or the micro-level in individual evaluations of lectures [SHJ10]. Moreover, student engagement is often connected to political engagement (such as student council or student parliament). But does political engagement and having good ideas for curriculum development automatically correlate? Is it not possible that many students can have good ideas about curriculum development but have no intention whatsoever in becoming politically active? Without judging this, shouldn't the goal be to get as many ideas from the students as possible?

These questions lead to one of the major premises of the new strategic instrument OpenBologna. The first hurdle of participating in curriculum development must be low. The different possibilities of doing so are described in more detail under *OpenBologna on an operational level*. Another key element of developing OpenBologna is the system of incentives. Students need to be intrinsically motivated; they need to know how their ideas will be handled and if they are going to be implemented. To a certain degree they also need *extrinsic* motivation, such as winning a prize or getting recognition for the best idea. Another aspect is that the majority of today's students have grown up with digital media [Pre01] and thus the possibilities of web 2.0 technology are also taken into account. In general, TeachING-LearnING.EU regards students as equal partners besides other stakeholders who are fostering improvement of German engineering education.

The following section clarifies the basic principles of the business strategy *Open Innovation*, on which OpenBologna is based.

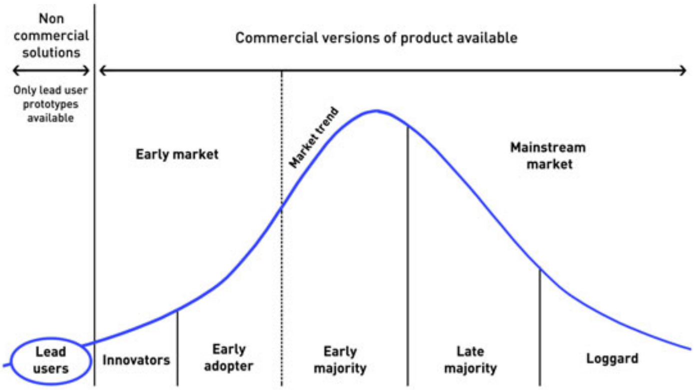

Fig. 2 Lead user concept [vH05]

2 What Is Open Innovation?

Being able to innovate is a key factor in a company's competitiveness. As a result in the rapid growth in markets in information and communication technology, combined with shorter product life cycles, global competition and heterogeneous demand of consumers, innovation management in companies has become quite complex. As well as (sometimes decades of) internal knowledge, many companies use the experiences and demands of their customers to improve products or services. The integration of external stakeholders into the whole innovation process has coined the term *Open Innovation* [Che03]. Apart from customers, other organisations such as research centres or universities can be involved in new product development. Not only companies but also public institutions gain many advantages by involving external stakeholders. In general, Open Innovation processes are quicker because more people participate but, by the same token, the approach broadens the scope for solutions as so many are brought to the table. Because of the direct integration of users, expensive and time-consuming market research can be omitted [Bre08]. Moreover, the acceptance of openly developed products is higher when compared to a traditional closed innovation process. Information about needs, problems and solutions are taken into account at an early stage of the development process; thus consumers tend to be willing to pay more for the co-developed product in comparison to a competing product on the market [FP04]. In a university context this means that students may be willing to invest more effort in a class if the teaching concept was co-developed by them.

A common approach in the research community and also in industrial practice is the *lead user method* [vH05]. Lead users are individuals that are experiencing needs ahead of the market trend and are at the beginning of the innovation process (see Fig. 2). According to Churchill et al. [CvHS09], lead users

> often both experience emerging needs and may develop prototype products and services that can satisfy these needs. Lead user prototypes can then become the basis for commercially attractive new products and services that will be appealing to routine users in the general marketplace. [CvHS09].

The implementation of the Open Innovation strategy is based on different relationships within a different framework, depending on the sector. At first glance it seems that the great success in the economic sector could be easily replicated by the educational sector, but in reality the transfer is not trivial. This transformation is discussed in the next section.

3 From Open Innovation to OpenBologna

The demand is obvious – more than ten years after the Bologna declaration has been passed, adjustments are still necessary. The European Ministers of Higher Education claim in the Budapest-Vienna Declaration in point 7 that they want to support 'efforts to accomplish the reforms already underway to enable students and staff to be mobile, *to improve teaching and learning in higher education institutions* [emphasis of the author], to enhance graduate employability, and to provide quality higher education for all.' [oHE10]

When using the Open Innovation approach to achieve the goal set by the ministers, some aspects should be discussed. The most pertinent questions are:

1. Are universities comparable to companies?
2. Does an "educational market" exist?
3. Can students really be regarded as customers of the university?

In order to answer the first question, the term 'company' needs to be defined. According to Sullivan [SS03], companies are organisations engaged in the trade of goods, services or both to consumers. They usually follow the principle of maximised profit [HL02]. In the case of universities, the "goods" of knowledge are provided through two core segments: research results and education. By paying tuition fees, students pay for their education; thus resulting in a trade situation. Since universities are nonprofit organisations, the companies' profit-maximisation approach is not applicable. German universities' financial status relies heavily on third-party funding for their research, the amount of which can of course be maximised but, as discussed before, without monetary profit. In terms of education, the number of students who graduate could be compared to "profit" – at RWTH Aachen University, for example, it is the mission of the Future Concept for Excellent Teaching to increase the number of students who graduate from one enrolment cohort up to 75 % [Uni09].

The second question (concerning the existence of an educational market) is closely linked to the first. It is obvious that universities compete with each other – for the best academics, for funding and for the best students. Globalisation intensifies this competition even more since it multiplies the alternatives (at least for academics and students) and enlarges their scope of action. The new trend of many universities putting a lot of effort into marketing activities also shows that certain measures from industry find their way into the educational system. Without any judgment of this trend, the situation seems to be a positive one for the "education market".

In order to answer the third question (whether students can be perceived as customers of the university), the term "customer" must be defined. In general, a customer is a person who buys goods or services [HAMT05]. A more economic viewpoint defines a customer as an individual or a party on the demand side of the market, which can consist of individuals, institutions or organisations with several decision-makers. According to Rogall [Rog00], in a market situation, a customer has the ability to choose between different products and suppliers. What is interesting now is that Rogall does not include the aspect of payment in his definition. Since students stand on the demand side of the education market and have the ability to choose between many different universities, they can therefore be considered as customers. According to Hees and Isenhardt[HI05], science always has many "customers", from ministries or project-executing organisations to students and citizens. The most important precondition for the relationship between customers and organisations is *partnership* [HI05]. The characterisation of students as partners has also been claimed by the European Ministers of Higher Education. The Prague Communiqué of 2001 [oHE01] says:

> Ministers stressed that the involvement of universities and other higher education institutions and of students as competent, active and constructive partners in the establishment and shaping of a European Higher Education Area is needed and welcomed [. . .] Students should participate in and influence the organisation and content of education at universities and other higher education institutions.

The discussion above leads to a key understanding of the role of universities and students. Universities are not entirely comparable to companies, but share some characteristics. They provide the "goods" of knowledge through education, and students are the main customers for that "product". The relationship between universities and students should be based on partnership. Universities compete against each other on the educational market for these customers – at least for those who are most likely to graduate. Therefore universities have a strong interest in the quality of their education as one of their core products. Following the principle of Open Innovation, students' experiences and requests can support the university to improve its "goods" in terms of education.

Putting the theory of the transformation from Open Innovation to OpenBologna into practice, the operational design of OpenBologna is described in detail in the following section.

4 OpenBologna on an Operational Level

In TeachING-LearnING.EU, the strategic instrument OpenBologna has been used from the very beginning. Each semester there is an *ideas contest*, a very common Open Innovation method. It is characterised by a high degree of freedom and the immediate generation of innovative ideas [PI09]. As a by-product, it also serves for the identification of lead users [PW06]. Topics are teaching and learning in engineering education. By awarding the best ideas with a prize, the students are motivated by extrinsic incentives. The first and second ideas contests were sponsored by famous tool suppliers (Bosch and Hilti).

In addition to the ideas contests, TeachING-LearnING.EU uses the *lead user* approach described earlier. Engineering students who are interested in the development of teaching and learning are identified, the goal being the improvement of teaching and learning concepts in engineering education, not a general facilitation of degree programmes. Based on the experiences of Open Innovation, the acceptance of new concepts developed by students is quite high. The first lead student workshop will take place in Aachen in November 2011. Adopting the slogan "LearnING by DoING", students are invited to develop innovative teaching concepts that foster practical competencies for engineers. After the workshop, lead students will present their ideas to the Community of Practice of TeachING-LearnING.EU in order to see if their concepts can pass the "reality check". The whole process of OpenBologna is visualised in Fig. 3.

In order to promote the concept of OpenBologna nationwide, it is important to reach as many students as possible. Publicity channels include the website (www.teaching-learning.eu) which publishes engineering education related news on a weekly basis; a facebook page which is also connected to the news service via an RSS-feed; and a Youtube channel where self-produced video interviews with different stakeholders are regularly published. In the first 17 months online, the Competence and Service Centre collected approximately 694 contacts.

Illustrating the potential outcome of the strategic instrument OpenBologna, the results of the first ideas contest are presented in the following section.

4.1 First Results: The Outcome of the First Ideas Contest 'Tweak your Bachelor's!'

In the winter semester of 2010/2011 TeachING-LearnING.EU ran the first ideas contest of the project. 37 ideas in total were submitted. The method of choosing the winners was as follows: Of each idea that had been sent in, a short version was created. All the team members of TeachING-LearnING.EU in Aachen awarded scores for the ten best ideas, from ten points for the best to one for the tenth best.

The top ten ideas were openly discussed within the teams at Aachen, Bochum and Dortmund. Each group had to select the three best ideas with no regard to the former ranking of the top ten. Additionally each group had to nominate a student, who also

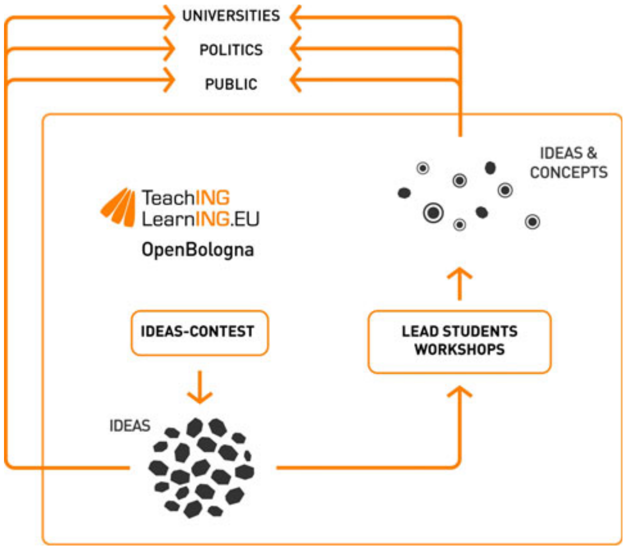

Fig. 3 Illustration of the strategic instrument OpenBologna

had one vote. Out of these six votes, the winning ideas were identified. The three winning ideas are presented below, together with their short version descriptions and the statements of the jury.

4.1.1 First Place: Engineering Social Learning Network – Study and Meet New People!

Description:

The semester begins. You are one among many. Different city, maybe even a different country – in any case a thousand new faces. The content is hard, the professor is alright but with hundreds of people in the lecture hall many questions remain open. The solution: the Engineering Social Learning Network called INGe! You can register for free and leave a little data, e.g. gender, semesters already accomplished, language(s), subject, preferred study group size etc. INGe now creates study groups by chance, depending on the matching of central criteria (language, subject. . .), either according to a special lecture or in general for the subject. At the same time, INGe gives the suggested participants the possibility to chat in a forum and to send each other messages. Thus the group can arrange a first meeting quickly which can be entered in INGe's calendar tool. INGe also suggests one of the study rooms of the uni. That way you kill two birds with one stone – study for the uni and meet new people!

(Sebastian Nowroth, student of metallurgy and material engineering, RWTH Aachen University)

Jury:

The social learning network absolutely fits the ground rule of TeachING-LearnING.EU: that all new teaching and learning ideas need to be designed for the digital generation. It supports the students in organising themselves in a way that goes beyond providing learning material. By combining a digital platform with real study meetings, it also includes the social side of the Bologna Process which, according to many experts, still needs attention. Its non-subject specific approach helps to improve learning in engineering sciences on a wide basis.

4.1.2 Second Place: More Groupwork and Communication Training

Description:

There should be more group work. In our case we have group work in the first and second semester, but from that point on not anymore. Now I realise that later in the daily working routine of engineers it is expected that they are capable of dealing with group dynamics. Communication is such an important topic. I know at first hand that it is important to enforce such things. In the uni we have 99 % ex-cathedra teaching, where you basically never have the chance to play a part in the lecture! There are as good as no projects that need to be done.

(Felix Büsing, student of automotive engineering,
RWTH Aachen University)

Jury:

To integrate more group work and communication training into curricula is not a new idea – at least within circles of engineering education or didactical experts in general. From a student's point of view it deserves full credit, especially regarding the criteria quality, implementability and effectiveness. Group work and communication training fosters the employability of the students and is also of benefit to each student's personal development. It is implementable in many different subjects.

4.1.3 Third Place: Uni-(Wiki)pedia, Filled by Teaching Staff and Students

Description:

In the first years of studying you are confronted with plenty of new stuff. A lot of the time you learn in an "exam oriented" way due to a lack of time. You don't understand the topic completely and forget it again quickly. Content you have covered is required throughout the course of your studies, especially mathematical topics. If you can't remember things, you have to do time-consuming research in order to fill your knowledge gap. Search pdfs, type in passwords, skip through scripts and notes and sometimes also video material. If nothing helps you have to go to the library or the confusing internet. My proposal is to connect content from the internet with the possibility to communicate about it. For example, the Taylor series is used for a derivation. If a student doesn't recognise it, he can ask a question which is *visible to everyone. This could appear next to the text. In the answer (students as well as teaching staff can answer and everyone can view it) there could be a link to the cumulated content available for the Taylor series (e.g. short definitions, lecture transcripts where the topic has been covered, videos, exercises with solutions and links to literature which is available in the library). That way resources from a faculty, a university or many universities could be connected. Students should also have access in order to inform themselves about the content of different studies and prepare themselves better.*

(Felix Moog, student of mechanical engineering,
Leibniz University Hannover)

Jury:

Having a wiki specially for engineering content with the capacity to exchange learning material and communicate about the given content combines communicative and meta-communicative aspects and therefore helps the students to understand the content on a deeper level. The idea also has the potential to improve teaching as staff can easily see which parts of their lecture cause problems among the students and bear repetition and clarification.

4.2 Interpretation of the Results

A wide-ranging spectrum of ideas was submitted. Some are very thoughtfully conceived, others are just shorts flashes of inspiration, for example:

- *Could the teachers please use green laser pointers instead of red ones? You can see them much better.*
- *More groupwork in all study courses (social competencies).*
- *Strengthening humanities.*

This lack of elaboration should not be viewed as a lack of quality because, although they have the characteristics of catch-phrases, they are valid observations.

Many ideas were combined with a general criticism of the educational system:

- *I think your campaign is really good because there are indeed some things to criticise.*
- *Every semester we have the situation that graduate engineers leave the uni who are interpersonally retarded.*
- *It strikes me that many exams have the goal to memorise absurd devolutions of actions or law texts which are forced by the chairs, in order to depict them one to one.*

These comments were offensive in parts and one could argue that this is not the right way to constructively present ideas for improvement. Nevertheless, for the purposes of evaluating the ideas the insults were ignored and did not appear in the short versions which were rated by the jury.

Another interesting aspect was that some students proposed the same concepts that are currently being discussed and praised by the engineering education community. Although they might not be innovative from the community's perspective, they underline the students' need for these didactical concepts.

Different learning types:

- *There are different strategies to configure your studies; everybody needs to find his or her own way. For that, it could be useful to find out the strategies with which others master their studies.*

Practical application:

- *In general, practical application is very important. One or two construction projects make a lot of sense. Like in coding tasks. But simulations should also be obligatory in compulsory subjects for students nowadays. And not just the theory but also the practical application. For construction, a FEM-simulation should be taken for granted.*

The general feedback on the ideas contest was positive:

- *I'm really pleased that such an initiative exists, which has set itself the goal to improve study conditions.*
- *I also want to contribute some hopefully new ideas soon – it's a great opportunity to do so!*

Only one participant was sceptical:

- *Apart from that, this here probably won't change a lot.*

To sum up the reflections on the first ideas contest, it is important to compare the results with the original aims of this part of the OpenBologna strategy. If at first sight the number of ideas is compared to the number of students enrolled in engineering science in Germany, the participation appears frustratingly low. However, TeachING-LearnING.EU takes a different perspective. If not for this contest, these ideas would probably never have been voiced – if at all, it would have been in a soon-forgotten (and certainly unpublished) conversation with peers in the cafeteria. Through the instrument of the ideas contest within the framework of OpenBologna, students were given a voice in the debate about how to improve engineering education in Germany and their ideas are subsequently being presented to experts, to political decision makers and to the public. From an economic point of view, the goal of expanding the scope for solutions by including students in the conversation has been achieved and it is illuminating to see that some of the ideas match those of engineering education researchers.

4.3 Putting Words into Action

An important and pending question is what will happen to the ideas after they have been handed in. TeachING-LearnING.EU takes a supportive role, rather than forcing teaching staff to implement the new ideas. The first step to realising the ideas is to promote them. All winning ideas will be presented at the annual conference, attended by teaching staff, including working groups with high ranking people (e.g. teaching deans). The ideas are going to be published by TeachING-LearnING.EU and will be distributed amongst the teaching staff of the three universities and via download on www.teaching-learning.eu. But promoting the ideas is not enough. TeachING-LearnING.EU actively tries to match the students' ideas with potential implementers (e.g. lecturers or teaching staff attending upcoming events run by the Competence and Service Center). The implementers commit themselves to pushing forward the realisation of the idea in their organisation. TeachING-LearnING.EU will request regular updates about the state of implementation and the quickest implementer is awarded *TeachING-LearnING.EU Maker of the Year*. With this approach, TeachING-LearnING.EU overcomes the problem of financing, appeals to the goodwill of the engineering education community and shows appreciation for the implementers. The matching of ideas and implementers at the conference ensures that everyone is "on the same page" and fosters an atmosphere of change through shared responsibility.

5 Conclusion and Further Research

The results of the first ideas contest of TeachING-LearnING.EU have shown that the strategic instrument OpenBologna can be a supportive element in the involvement of students in curriculum development. The next step will be to garner support from different levels within the universities in order to put the ideas into action. To ensure the effectiveness of OpenBologna, it has to be ensured that as many ideas as possible will be translated into actual curriculum development. To start the process top-down, the new ideas will be presented at TeachING-LearnING.EU events, as well as in smaller circles with decision makers of the universities. They are being trialled prototypically in teaching experiments in order to get direct feedback from students and teaching staff and will be presented in the next call for Flexible Funds in order to give teaching staff ideas for their own projects, sensitising them to students' ideas and inspiring them to improve their lectures with the financial support of TeachING-LearnING.EU.

The first ideas contest helped to broaden the scope for solutions for curriculum development and showed that students can be reliable partners, especially when it comes to new teaching concepts tor the digital generation. It has to be pointed out, however, that the topic of the first ideas contest was somewhat general and it will be interesting to see if the quantity and the quality of submissions will change with more specific topics in subsequent contests. The results of the first lead student workshop are also eagerly awaited, as this method is expected to elicit more detailed solutions (something like prototypes or further developed products). It will be interesting to identify the major psychological motifs of the students as they participate in curriculum development processes. This will inform the further implementation of OpenBologna within TeachING-LearnING.EU and in other universities in the future. The critical question is whether students would be willing to invest more time in their studies if the teaching concept is co-developed by them. In order to standardise the instrument OpenBologna and to measure its efficiency, the development of a management control system could be useful in the future. This could help to implement the strategic instrument in future curriculum development on a sustained basis.

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Resisting Time Pressure

Work-Integrated Learning Facing Individual Challenges in Knowledge-Based Economies

Sven Trantow, Janine Stieger, Frank Hees, Sabina Jeschke

Abstract The contemporary economic and working environment is more complex and turbulent than ever before. On the one hand, enterprises must succeed in turbulent and fast changing global markets. On the other hand, traditional models of the regular employee have been substituted by dynamic biographies. Nowadays, individuals are required to refresh their knowledge and modify their skills constantly and for a long working life while organizations have to use efficient instruments for the flexible transfer of work-related knowledge. These enhanced requirements of individual qualification and competency development conflict with the increasing time pressure of the economic and everyday life.

This paper firstly analyzes lifelong learning and continuous competency development as essential requirements in a modern working environment. The socioeconomic dilemma, *Time for Learning Processes vs. Time Pressure*, however, shows that in the tightened conditions of today's economy the fulfilment of these requirements can only be obtained by innovative forms of work-integrated learning. Based on these results the paper finally describes the concept of Microtraning as one example of an efficient method of work-integrated learning and powerful measures to face the dilemma described.

Key words: Modern Working Environment, Knowledge-Based Economy, Individual Challenges, Lifelong Learning, Socioeconomic Dilemma, Time Pressure, Work-Integrated Learning, Microtraining

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1 Organizational and Individual Challenges in a Modern Working Environment

In the past two decades, all modern societies have experienced profound changes in socioeconomic terms and have undergone far-reaching processes of change both in economical and social structures [BH09]. With regard to the velocity of change, the complexity of structures and the dynamic of processes, it is uncontested that today's socioeconomic environment is more turbulent than ever before.

This growing *dynaxity – a coinage to comprise the growing dynamics and complexity of the globalized society in one term* – is connected with incisive changes of the occupational distribution within a modern working environment [HHH09]. With the shift towards a service-oriented (tertiarization) and knowledge-processing (quartiarization) economy, human potential becomes increasingly important for added value and competitive ability [Edv02]. Accompanied by the tightening of demographic change and the increasing lack of skilled workers, intellectual capital and intangible assets increasingly surpass the value of any other resource [EM97].

Against the background of today's dynaxity, in a service and knowledge-based society, organizations must face various challenges to be sustainably successful. One of the most important of these challenges is a steady pressure to innovate. Accordingly, an organization's capability to assert itself in the global market is increasingly based on the capability to innovate. As human knowledge, creativeness and originality are central preconditions of innovations, management of human potential and intellectual capital becomes crucial:

> It is really quite simple. Innovative organizations are places with innovative people. The strategy question has to be: 'How do we develop the capacity to innovate residing in our employees?' [Lun08]

To sum up, then: In the complex and dynamic markets of today's economy, the knowledge and skills of employees acquire central importance for the innovative capability and the competitiveness of organizations. The strategic development of employees' skills and knowledge thus constitutes an important investment in the intangible assets of a business, as the most valuable resources of companies in service and knowledge-based societies. Employee development or learning thus shifts from an organizational cost factor to a key factor in ensuring the innovative capability and sustain competitiveness of enterprises.

While organizations deal with the question of how to use and develop knowledge among their employees, employees face profound changes in their working environment which confront them with challenges both in their private and professional life [Opa08]. Accordingly, the future working environment is increasingly characterized by flexible working time, place and biographies [Voß98]. The erosion of traditional labor conditions and the extension of precarious employment and continuous occupational change strides ahead [Bau09]. Increasingly, safe jobs are replaced by self-employment, freelanced project work and temporary unemployment. As a consequence fixed term jobs or the "job for life" become an exception and secondary jobs and part-time employment become standard [Dah09]. Already today, many employees are nomadic workers, multiple jobbers or mini jobbers – the former working paradigm of the regular employee will be replaced by dynamic biographies.

Amidst such job uncertainty, the ability to adjust and the ability to be flexible become indispensable characteristics of contemporary employees [HHH09]. To meet these requirements, individuals are required to refresh their knowledge and modify their skills constantly, especially given the exponentially growing amount of knowledge and its shrinking half-life [Sie04]. Knowledge and skills gained in primary occupational education no longer suffice for a whole working life so that lifelong learning and continuous competency development become essential requirements to face the individual challenges of a modern working environment.

2 Time for Learning Processes versus Time Pressure

As described above, in times of turbulent and dynamic markets, lifelong learning as well as continuous competency development become essential requirements for individuals and also key factors for the innovative capability and a sustainable competitiveness of organization. However, in this context individuals as well as organizations are confronted with an apparently unsolvable problem: on the one hand, the complexity of the modern working environment demands continuous learning and competency development; on the other, the same socioeconomic climate fosters particular *time pressure* on employees, limiting the time available for the kinds of personal development demanded. In other words: The "dynax" conditions of modern service and knowledge-based societies call for measures to develop human potential, whose realization they inhibit through using up the necessary time. The requirements of continuous learning and competency development caused through complex and dynamic environments paradoxically conflict with the increasing time pressure of the economic and everyday life – the Catch 22 of a modern work environment.

The interdisciplinary research and development project "International Monitoring"[1], which is funded by the German Federal Ministry for Education and Research and the European Social Fund, identifies the corresponding dilemma "Time for Learning Processes vs. Time Pressure" as one of the central socioeconomic problems of modern working environments. The identified dilemma describes the individual, organizational and social necessity for learning and development processes under conditions of increasing time constraints in everyday work and life.

As innovations decisively depend on the human potential of employees and the readiness of enterprises to evolve, a lack of learning processes induced by time pressure constitutes a serious obstacle to innovation and competitiveness. At the in-

[1] Coordinated by the institute cluster Institute of Information Management in Mechanical Engineering (IMA), Center for Learning and Knowledge Management (ZLW) and Ass. Institute for Management Cybernetics e.V. (IfU) the central aim of the project is to identify and structure the main challenges of individuals, organizations, networks and societies in a modern working environment as well as to analyze global approaches for the efficient handling of these dilemmas.

dividual level, the individual employee must balance working against learning in the tight conditions of a modern work environment. At the societal level, demographic changes to the workforce must be tackled: here, one of the central tasks lies in integrating a cross section of groups across all phases of life into the work process. This means safeguarding employability into old age, integrating people with disabilities into the mainstream work environment, improving equal opportunities, and ensuring work-family balance for employees. In order to reach this goal a reconceptualisation of education is needed from fact-oriented procurement of knowledge towards competence-oriented empowerment [Dah09].

The dilemma elucidates the urgent requirement for new ideas on the design of learning and working environments to face the individual, social and economic necessity of continuous development of human potential against the background of increasing time pressure. The question of how best to deal with the dilemma "Time for Learning Processes vs. Time Pressure" is thus one of utmost importance for sustainably encountering the challenges of a modern working environment.

3 Resisting Time Pressure through Work-Integrated Learning

> We learn how to do things by doing the things we learn. (Aristotle)

To efficiently deal with the described dilemma first of all the traditional separation of learning and working has to be overcome. The change to a service and knowledge-based society and dynamic economic environments requires new strategies of education and learning while the traditional educational system cannot sufficiently provide all the knowledge required for the working process [Bea04]. For this reason, Sauer differentiates between *further education* and *further learning* as two different forms of professional development [Sau09]. Whereas further education comprises institutionally bound learning and thereby excludes the working sphere from the learning process, further learning follows the logic of individual professional activities and therefore comprises continuous work-integrated learning processes.

This concept of further learning is based on the idea that the successful integration of learning and work is an important factor for an efficient continuous learning and competency development. As time pressures increase, and whilst further education remains institutionally separated from the workplace, learning surroundings fail to meet the requirements of a modern working environment. On the other hand, the integration of learning and work offers fast, flexible, individual and cost-efficient knowledge acquisition and competency development.

Integration of work and learning, however, is not a new research area. Many attempts at integrating work and learning can already be observed – although it is important to note that such approaches vary greatly, particularly regarding the format of work/learning integration utilised. A telling illustration is found in the sheer multitude of concepts observed in this research area: from work-integrated *learning, close-to-work learning, work-related learning* and *work-based learning*, to *learning at work* or *learning in the process of working*. In part, such terms are used synonymously; however, in other instances each concept adopts a distinct position. To focus on commonalities, some recurring key words or distinctions amidst these different vocabularies of integrated work and learning include:

- Workplace-bound or workplace-related learning
- Non-formal or informal learning
- Implicit or explicit learning
- Intentional or non-intentional learning
- Self-directed or externally controlled learning [Deh03].

According to a comprehensive definition, work-integrated learning concerns learning processes that have a direct topical and spatial relationship to work. The learning venue equals the work place, or is at least spatially connected to it, in order to address both workplace-bound learning and work-related learning. Work-integrated learning consists of both didactically and methodologically pre-processed non-formal learning processes that are often (additionally) supported by a tutor (a teacher/superior etc.) and informal learning processes, whether they are intentional or unintentional. Informal learning processes here can also be instigated through non-formal learning in the non-formal learning environment (e.g. exchange/discussion with colleagues, teamwork etc). Beside externally-controlled learning processes in which learning goals and content are delivered in a top-down manner, self-directed learning is also part of work-integrated learning. Here, with the background of his individual specialized knowledge and experience, the learner can expand knowledge and skills individually, tailored for his own needs (bottom-up). Ultimately, the expanded notion of work-integrated learning comprises both explicit and intentional learning and implicit and non-intentional learning. The advantage of explicit and intentional learning – both the externally controlled variation through designation of learning content and goals by e.g. a trainer/tutor and the self-controlled one – is a higher grade of controllability and adequacy of the whole learning process.

To address this dilemma, “Time for Learning Processes vs. Time Pressure” then, the main advantages of work-integrated learning are seen in terms of time- and cost-efficiency and flexibility, as well as its practice-orientation. Accordingly, work-integrated learning enables employees to learn at their workplace and at the same time reduces the effort of transfer in the everyday working life. It enables employees to develop their skills and qualifications relating to the particular potential, problem or situation [BH09]. Thus, work-integrated learning especially is the acquirement of necessary enterprise-specific knowledge which employees develop through handling of their tasks and concrete problems. The learning venue for this type of knowledge is not the classroom but the workplace within the entrepreneurial context itself [Bea04]. Through this means learning processes can be designed as an active and problem-solving perusal of authentic demands in real-life work and production processes [Ste00]. The learning demands of the employees can be satisfied because they are able to expand their knowledge and skills individually. This type of self-controlled learning at the workplace thus meets today’s situation of dynamic biographies and the requirement for lifelong learning since it fosters the self-reliance and the personal learning competence as essential key qualifications of a modern work environment [DS07].

Against the background of the growing importance of further learning in today's fast changing environments, formalized further education gradually becomes less appropriate, since it lacks flexibility and practical application and is often too expensive in terms of time and money to be a workable solution. In order to support and enable work-integrated learning, organizations are therefore called to further develop existing types of work and learning arrangements as well as to establish new learning environments that support learning process by means of innovative forms of learning media. In the remainder of this paper, one case study of a particularly successful learning arrangement is examined.

4 Microtraining – An Innovative Form of Work-Integrated Learning

> Microtraining is for me something that the corporate sector has been longing for, for a very long time and especially the small and medium sized businesses. (Lennart Sundberg, Sweden, Director *Knowledge Activating Group*)

'Microtraining'[2] is a flexible, interactive and time-saving method for sharing knowledge by using the expertise of everyone in an organization. Microtraining supports non-formal and informal learning processes, focuses on the individual participants and encourages active learning to transfer knowledge between people. The particular Microtrainer does not need to be a professional trainer, but rather can comprise any person in an organization who likes to share knowledge, improve communication and learn from his or her employees or colleagues.

Microtraining sessions can take place anytime and require limited time for preparation and execution. It is best to choose a time that fits the work schedule of the organization. A typical Microtraining unit is characterized by a duration of approximately 15 to 30 min. The relatively short time is important with regard to learning in the course of working. Learners consist of people who work in fixed shifts or on location such as production staff, installers, builders, sales people etc., from which at least some would lose interest or would be overstrained by longer learning units. The learner group has to be large enough to allow a discussion, but should not consist of more than five to seven people to avoid passiveness.

Each Microtraining unit begins with a short 'warm up' exercise to introduce participants to the topic and by pointing out the goal of the unit. Furthermore, a short (multimedia) demonstration or exercise introduces the participants to the topic. These first sections are followed by a phase of discussion and feedback in which questions are asked to stimulate the group of learners to actively share their

[2] The Microtraining method has been developed in the research project Microtraining coordinated by the Delft University of Technology (http://www.microtraining.eu/) in cooperation with the institute cluster IMA/ZLW & IfU.

(tacit) knowledge. Through these questions it becomes possible to check if the input was understandable for all participants. In the final phase of a Microtraining unit, a short summary of the learned content is provided, underlining the main learning achievements for the users and giving a short preview of further units in order to stimulate interest in visiting following learning units. Should more than one session be necessary to deal with a topic in a suitable way, the Microtraining cycle will be divided into several sessions focusing on sub-topics. The introductory session is designed to get the discussion started. Concluding sessions are reserved to connect to the next cycle of sessions focusing on a new topic.

The short Microtraining units are aimed at encouraging self-determined learning and are provided periodically. The whole concept of Microtraining becomes ever more important against the background of the requirements to lifelong learning and continuous competency development and as a mean of custom-tailored qualification on demand instead of "learning on stock". Especially occupational categories without multimedia access for educational use can be reached considerably better [DVB08]. This method increasingly emerges as an innovative instrument for work-integrated learning in a modern working environment.

5 Conclusion and Prospect

The dynax working environment of today's knowledge-based economies places high demands on organizations and individuals. Even though both have a common interest in efficient measures of knowledge transfer and skill development, the continuous acceleration of operational business and everyday work often inhibits their realization. To deal with the dilemma Time for Learning Processes vs. Time Pressure, the integration of work and learning is inevitable. Flexible, timesaving and practice-oriented concepts of work-integrated learning play a leading role in mastering the challenges in knowledge-based economies.

The Microtraining method is an example for a successful work-integrated sharing of knowledge by using the expertise of everyone in a given organization. While Microtraining is decentralized and is not hierarchically controlled it posed particular demands on management, employees and organizational structures. It is a central future task to find out what these demands are and in what manner individuals and organizations have to change in order to apply Microtrainings and other types of work-integrated learning in an efficient and sustainable way.

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An Approach for Integrating Simulation Games in Higher Education

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Abstract The “new learning generation”, the so-called “Digital Natives” or Generation@, grows up with more and more information and communication technologies (ICT). The characteristics of this generation are to be considered while planning or improving a lecture to meet the students’ new skills. Simulation games play an important role for modern learning scenarios, because they are a cost-effective way to improve learning processes. As a part of the changeover to the Bachelor/Master-System in the European Union, there is the chance to make use of new concepts and methods, which utilize the new skills of Digital Natives and the along going mental models. The “German Chamber of Industry and Commerce” (DIHK) recently criticizes that the education of German universities does not prepare the students for their later work life very well. To overcome such situation simulation games can be used to give students the opportunity to apply the content of a lecture in a virtual environment. Specially lectures with high student numbers, e.g. the lecture “Computer Science in Mechanical Engineering” of the RWTH Aachen University is attended by more than 1400 students each summer term, web based simulations are an efficient way to give students an idea of the practical application of the theoretical knowledge gained in the lectures. We developed a framework for simulation games in higher education, which offers an easy way to enable students to apply the taught knowledge. To evaluate our framework the traditional learning concept of the lecture “Project Management for Physicist” (with about 100 students) is actively supported during the summer term 2011 by an online simulation game providing the students a way to utilize the content of the lecture.

Key words: Simulation Game, Project Management, Lecture Concept, Transferring Skills and Disciplines, Mobile Learning, Serious Games, Digital Natives

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1 Introduction

With the Bologna Process Europe started to face the challenge to modernize its education system for a sustainable learning environment for the upcoming generations. Over ten years after beginning the process, the first graduates enter the work life in industry. First surveys show a positive response on the process, but also reveal a few drawbacks. Action competences and the utilization of the gained knowledge are the most named characteristics, which employers miss when graduates enter industry.

In this paper we design a concept to integrate simulation games in higher education for teaching students action competences and enable them to utilize the taught knowledge. By doing this we point out, that because of the advances in technology and the different handling of it by the younger generation, simulation games are an efficient way to do so. The development of the game is based on a newly designed framework [Pre01], which will give administrators a basic system with the option to put in individual content. The framework is currently tested in a lecture of our institute. Traditionally, the concept of the course consists of a frontal teaching course, a two-day real life simulation game called "laboratory" and a final exam. During the two days of the real life simulation students construct a soapbox racer to experience working in task-oriented teams and internalize the content of the lecture. The laboratory is well received by the students, but is too short to reflect all aspects of the mediated content. For this reason we created the online simulation game, which is played during a three weeks period prior to the laboratory. After this time the experiences made online can be internalized and used during the laboratory. Against this background the article discusses the approach and gives a short introduction in the online simulation game framework and its application. It also discusses the advantages of the new approach combining lectures with real and online simulation games. Finally, an outlook for other scenarios of usage of the approach and the framework will be given.

2 A New Learning Generation in a New Education System

The technological progress over the past three decades has emerged the need for new teaching and learning concepts. Especially media related innovations in spreading of and interacting with information have changed the way knowledge is received. People from this era have different mental models on which their learning model is also shaped. Persons who are related to this impact are named Net Generation, Net Kids, Generation X or Generation@ [LBS09]. There are three main aspects, which narrow the term 'generation' further down in this context:

1. The generation is born after 1980.
2. Since their early childhood the generation is in touch with Information and Communication Technologies (ICT) and is familiar utilizing them in different situations.
3. The generation has specific characteristics, which affect learning and study habits (e.g. rapid acquiring of information, networking, focus on teamwork).

The skills of this generation are not addressed by the existing educational system. Therefore, the demand for a change of the system is often based on the aspects of this emerging generation. Prensky [Pre01] coined a term, which fits best regarding to the fact, that those people grew and still grow up with advanced ICT: ‘Digital Natives’. “Our students today are all “native speakers” of the digital language of computers, video games and the Internet” [Pre01]. But what are the main differences, concerning the learning and study habit, which must be addressed, when planning a course for Digital Natives?

2.1 Digital Natives – The New Learning Generation

The previous paragraph mentioned the specific characteristics of Digital Natives, which affect their learning and study habit. The following points sum up the most important ones:

- Digital Natives spend a lot of time with ICT. Some surveys state, that German teenagers spend more hours on the Internet than watching TV. Forecasting current statistics of usage, a child has spent 15,000 hours until it is 20 years old. This is equivalent to the effort one must invest to become a professional pianist [Gas09].
- The identity of Digital Natives is more and more developed online, whereby the border blurs between online and offline for the kids. Developing identity online means on the one hand to receive information to build up knowledge and opinions. On the other hand it also means to socialize with others over the Internet by using social networks like Facebook, Twitter or MySpace.
- People who belong to the Digital Natives are not solely passive recipients of content. They produce it by themselves by combining, sharing and putting up content on their blogs, video-portals like Clipfish, YouTube or discussion forums. This is not only done alone. New ICT enables the Digital Natives to collaborate. The best example in this case is Wikipedia[1].
- Finally Digital Natives have new ways of finding, rate and reuse information. They are familiar with reading short text content, watching multimedia clips and digging deeper in selective topics if one is interested. This means they receive the content quite non-linear and can switch quickly between different types of media [Gas09].

Summarising, it can be stated that Digital Natives have a different way to acquire knowledge. Through the development of ICT they developed new skills and behaviours to find and reuse information. This is done in a collaborative way due to the communication possibilities based on the Internet. So why not utilize ICT more for teaching and learning purposes? Not only to transfer knowledge in the sense of hard facts which is done through lectures and courses but also to improve existing knowledge and enable the application of it.

[1] We note that Wikipedia is not build up without exception by Digital Natives. But a survey from 2010 [GG10] showed that three quarter of the contributors are at the age of 10 to 29.

Table 1 Combined ranking, Graduates & Employers (extract) [GW03].

Description	Combined ranking
Capacity for analysing and synthesis Capacity to learn Problem solving	1
Capacity for applying knowledge in practice	2
Capacity to adapt to new situations Concern for quality	3
Information management skills Ability to work autonomously	4
Teamwork	5

2.2 Enabling Digital Natives Applying their Knowledge

The idea to give students the chance to apply some content of the lecture to relevant facts is very common. Most lectures offer in addition to the weekly frontal course lessons, in which the theory is applied by solving exercises. So students may reflect the matter of a lecture on an individual level. According to Le Mar [LM01] the following levels of recursion are distinguished: individual, bilateral cooperation, team, organization and network. By default students reflect on an individual level. Sometimes a few students work together to solve exercises. Then they reflect also on a bilateral cooperation level. But in the later work life people most of their time work in teams and complex enterprise environments, for which they are not well prepared during their studies [LM01]. For example a recently conducted study of the "German Chamber of Industry and Commerce" (DIHK) showed that 25 percent of the participating enterprises, which fired new employees in their probation period criticized the lack of the ability to transfer their specialist knowledge into business practice. Soft skills play an important role in this context. While working in goal-oriented teams is common in business, it is not addressed very well in higher education environments [Hei11].

The evaluation of the DIHK is quite new and is strongly referring to the current Bachelor/ Master process in Germany. But the demand for better transition of specialist knowledge and further competences of graduates is not a new, Bologna Process phenomenon. It will be around for all-time. In 2003 a European survey among graduates and employers showed, that competences in problem solving, which also means to transfer and utilize knowledge into different situations, is one of the most important skills for working life, followed by social competences like team work and communication skills (see Table 1).

Similar results were evaluated in other empirical studies among German associations. In 2001 an empirical survey among graduates showed that without interdisciplinary skills the capability of acting in business is nearly not possible. Beside methodological and organizational competences social skills are demanded as well and were highly rated as requirement for the work life [Bra09]. In 2005 an evaluation among graduated engineers pointed out, that the possibility to practice different competences should be given during study courses. Because professional and interdisciplinary competences work together in practice, students have to have the same opportunity during their studies [Bra09, FS05].

While the evaluation report of the DIHK strongly connects the missing skills of graduates with the Bologna Process, it is not just the Bologna Process, which changed the expectations towards the graduates and the education system. Also social changes influenced the discussion of the "new" graduates and the question, if their skills, abilities, competences are supporting the employability in the 21st century [Vbw11]. In Engineering the demands on students have grown from just technical expertise to various soft skills like social and communicative competences, foreign languages or flexibility on the job market [SHJ10]. In this context, the Bologna Reform Process can be considered not as a reason for this but a chance to include new demands in teaching. But not only the demands of the market have changed: Due to the spread of ICT in our daily life, the explosion of available information and the possibilities of global networking another essential variable of the equation has changed: the students themselves. Considering the characteristics of the Digital Natives and the Bologna Process as a chance for lasting improvements in higher education new methodologies have to be found to include the requirements in an efficient way. One way to face those challenges is introducing simulation games into innovative teaching and learning environments.

3 Simulation Games

Back in May 1956, the first computer-based simulation [ES00] was presented. The concept of the "simulation game" is much older. About 800 BC the simulation game "Chess" was developed, which is well known in the Western world.

The term "simulation game" comprises two different words. On the one hand is the "simulation", on the other hand the "game". A "game" could be described with four characteristics [GM95, Elg90]:

- Clear set of rules, which ensures a reliable application.
- The game develops in stages (indicates an underlying discrete model).
- It is a behavioural assessment.
- Games need an instrumental basis to perform.

The word "simulation" means an approach for analyzing systems that are too complicated for theoretical or formulaic treatment. Simulation or simulation behaviour means a temporal-logical structure of each action. From these two particular aspects the concept of "simulation games" has the following definition:

"A simulation game is a constructed situation, in which one or more persons act in a discrete model after defined rules, at which the showed behaviour is systematically tracked and can be evaluated after an explained calculus" [GM95].

Such board-based simulation games were developed at the Institute for Management Cybernetics of RWTH Aachen University (IfU). As one example we describe the simulation game "Q-Key". The goal of this game is to make players sensitive about quality management. There are five groups of players and each group is given the role of a department head in a fictional company. The products or services should be quickly directed through each individual department with the highest quality and lowest costs possible. The route the products take through the department is defined as much by the throw of the dice as by the decisions of the players. If a player's product lands on a 'chance' square, they must respond to a specific managerial issue. The game is accompanied by a software tool, which uses numerical data to illustrate the progression of the virtual business. With this it will become clear that the optimisation of individual departments can actually prove detrimental to the financial situation of the firm as a whole. Only optimisation across departmental boundaries will finally lead to increased business success [HSH03, Nuß04].

For board-based simulation games in a learning environment usually a game manager is needed, who knows the game, has to monitor compliance with the rules and applies any specific functions within the game. There are also players who carry out one action after the other. As a major drawback of a real-time simulation game in education environments the organizational aspects (schedule a date, where everybody is available, etc.) [Bau09] and the high costs of assistance [Roh92] can be named. But to overcome the drawbacks of board based simulation games, Internet-based simulation games are a good choice.

3.1 Internet-Based Simulation Games

Simulations have a widespread area of application. Pilots for example train in so-called "Simulators". Here the application of a simulation reduces the risks and the costs compared to a real flight [Haf00]. This application shows two important benefits of technology supported simulation games. On the one hand a potential reduction of costs by using virtual environments and resources and on the other hand, which is even more important, a reduction of the risks. In a simulation game the "player" is able to make mistakes without direct consequences for his real life. Generally one can speak of testing and exercising (new) concepts in a controlled environment and therefore learn something which can be applied in real life [Kub02]. While simulations for pilots aim on an improved interaction between the human and the machine, simulations for organizational purposes focus more on the interaction and relation between humans.

The benefits of simulation games are therefore in functional goals (the teaching of expertise on the functions and relations), in interactions (joint training and development of a "we" feeling), and in the enhancement of motivation (the belief in the needs of certain measures and practices) [Str03]. Ideally the learners are learning action-, and decision-making, as well as social skills through teamwork. In addition, knowledge about processes can be deepened in simulation games [Kel01].

Rohn [Roh92] appends that simulation games should use educational synergies. This allows "learning by doing", the opportunity to make mistakes and the possibility to transfer learned knowledge into given situations.

In an article Fischer [Fis06] mentions as the main advantages of Internet-based simulation games the big computational power, which allows the mapping of more complex models than in non-computational powered (i.e. traditional board-based) simulation games. Other advantages are:

- (The possibility of) direct feedback.
- Month (or years) can be simulated in a few minutes.
- A computer can better monitor compliance with the rules of the game.
- Less computational and administrative overhead for the organizer.
- Avoidance of mathematical mistakes.
- Discussions can be integrated (synchronous and / or asynchronous) in the learning surface. This leads to the creation of a virtual social environment.
- It is possible to adapt the learning offer to participants' specific needs [Kel01, RR01].

One disadvantage of – not only Internet-based, but also in general technology-based – simulation games is that the player must be able to use the offered technologies [Gab08] and it must be available to him. Another disadvantage is based in the real life equivalent. Working in groups means that there are a lot of underlying and invisible relations between members of a group. Mapping all this relations in an adequate way may make the creation of an internet-based simulation game very complex [Fis06]. Therefor there should always be an organizer or administrator of the game, who monitors the teammates and their behaviour between each other. Besides the monitoring an organizer has more tasks to fulfill during a run of a simulation game.

In a teaching unit the organizer takes an important role in the fulfillment of a successful implementation of the simulation game. He or she must clearly explain how the game score is calculated in the introduction.

The game score[2] should fulfill the following tasks:

- Illuminate the importance of experience for the participants
- Establish the facts, concepts and models, which were used in the simulation
- Determine the significance of emotions for the individual and for the group
- Look at the different views that the participants have made from processes and experiences. Thus, participants should be encouraged, to explore the complexity of the teaching system in depth and reflect on their acting in it
- Summarize the results of the game (e.g. decision making, problem understanding, knowledge, etc.)
- Generalize the results (game master and players try to generalize the results from the game)
- Transfer of the results of the game level into reality [Ste92, Tha86, Ker03].

[2] Also "Briefing".

Besides an introduction, in which the intention of the simulation should be explained, there must be an evaluation phase at the end of the game. Fischer says "especially in [pure] Internet-simulation games a good evaluation is critical for the success of learning, because the direct contact to the organizer is missing" [Fis06].

4 Simulation Games in Higher Education

The restructuring of the Bologna reform opened various possibilities to a strategic integration of practical elements in higher education. Regarding the design of the student's education the university assumes a comprehensive concept of competences. "Action Competence describes one person's capability for the successful accomplishment of new duties and responsibilities" [BHH07]. Action competence emerges through the interplay of different disciplinary, methodical, social, and personal competencies [SS92, Ber04]. Self-organized learning is a mechanism by which action competence will be acquired. This includes the moment of acting and learning as well as the motivation and the self-organized capability to fill the knowledge and ability to overcome gaps. Especially against the background of the increasing training of key qualifications during the schooldays particularly practical options for the training of competences in higher education are required. Brall et. al. [Kol74] developed a model of work-integrated learning, which is the didactic base for integrating our simulation game in higher education. The following paragraph gives an overview about the theoretical derivation of the concept and implementation in the lecture "Project Management for Physicists". Afterwards the design of a case study will be shown.

4.1 Work-Integrated learning

In the '70s David Kolb [Jar04] showed with his "Experimental Learning Cycle" that experience is an effective initial point of learning processes. This happens due to the reflection of experiences, the transfer into abstract models and the conscious appliance in new contexts. On the individual level of learning Peter Jarvis [JP01] pointed out that a person does not have to be forced to learn from every experience and that learning can take place on every level of consciousness. He distinguishes between incidental, implicit and explicit learning on the one hand and non-learning on the other hand. Unlike other forms of learning explicit forms contain a continuous loop with the elements practice, experiment, reflection and evaluation. Järvinen and Poikela [Sie06] showed that reflecting is the core element of adult´s learning. Only through these opinions, models and perspectives are formed which are the condition for new activities.

In terms of the sustainability of learning the experimental learning cycle of Kolb can be amplified with a second learning cycle which is not only based on a single experience. The second cycle focuses on the integration of different experiences

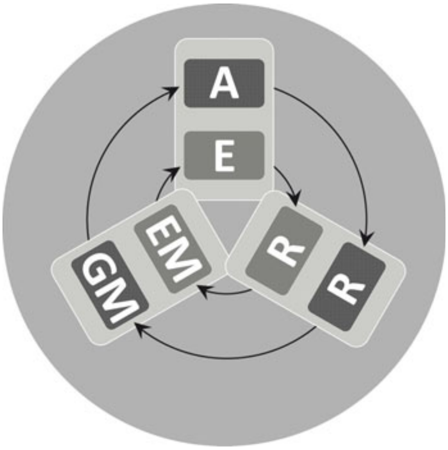

Fig. 1 Double cycle of action and reflection

and integrates them into a model of action. This model is improved by every new experience and can be shared with others. Based on this knowledge we can derive a model of work-based learning, which can be illustrated in a double action and reflection cycle (cf. Fig. 1). The cycle starts with a concrete experience (E). The mental models (EM) are formed by reflection (R) of the concrete experienced situation, which can be used in similar situations. If these mental models are deliberately implemented and result in an action, we can speak of an intended action (A), which is accompanied by new and unusual experiences at the same time. Now the intended actions, as well as the new experiences enter into the renewed reflection. A generalised mental model (GM) will be developed through the comparison with the previous experience-based models [Kol74].

While planning the lecture "Project Management for Physicists" the double cycle of action and reflection was considered. The course consists of a frontal teaching course, a two-day real life simulation game called "laboratory" and a final exam. During the two days of the real life simulation students construct a soapbox racer to experience working in goal-oriented teams and internalize the content of the lecture. The laboratory is well received by the students, but evaluations among the participants showed, that this event is too short to reflect all aspects of the mediated content. Because of that we implement an additional cost effective Internet-based simulation game in an adapted concept, to evaluate if the learning experience is enhanced.

4.2 The Simulation Game Framework

The online game is based on a self-developed framework, which provides an easy way to create games with different content [VdHMJ10]. The content of a new simulation game must be provided as a set of different and well-structured text-files.

Beside the possibility of using different content the framework provides the following important requirements for simulation game portals by default:

- Registration and User-Login (to save user-data, and to individualise the learning approach)
- Throwing of dices (function to map random events)
- Providing different actions if a gaming piece is dragged to a field (Bonus, break, self-centered, group-centered) with the option to implement more actions
- Forum-functionality to support communication between team members and other participants of the simulation game
- News-functionality (the organizer can provide news to all users)
- Game-History (the player can reproduce her or his decisions and actions)
- Statistics (provide a way to see the results of specific decisions and actions)
- User management
- Game management.

There are different implemented actions. On the one hand there are actions, which are related to the individual, and actions related to the group. Overall a competitive setup between different groups gives additional motivation to the students. With reference to Sect. 3, the framework supports a clear set of rules (each action has its own rules), each game is developed in stages (it is round based), it supports a behavioural assessment (the player can decide which move he or she will do next) and has an instrumental basis. Referring to the different levels of recursion [LM01] players get a direct feedback when applying an action (individual level), they have the opportunity to play interaction games with other players (bilateral cooperation level), the framework monitors the evolution of the game in terms of statistics (team level), and there is a platform for discussions accessible by all teams (organization level).

4.3 Case Study at RWTH Aachen University

As mentioned before our concept is being tested in the lecture "Project Management for Physicists" with about 100 students, which is held each summer term at RWTH Aachen University. Before introducing the virtual simulation game, the concept of the lecture was a traditional 1.5 hour lecture on a weekly schedule with an additional two-day real life simulation game in the form of a block tutorial. The lecture pursues the following educational objective, with which the students should be able to …

- …plan and to realise complex projects on time.
- …include structural and procedural requirements of an organization into the planning.
- …analyse and design communication process in teams, task roles and problem-solving strategies.

Positive experiences were made over the last years with the block tutorial where the students go through one complete project management cycle. The task of the

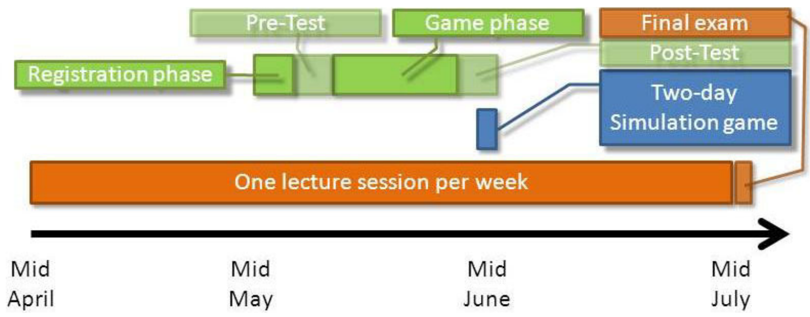

Fig. 2 Timeline of our case study

students inside this tutorial is to build a soapbox in groups of about 20 students. In a first step they got only the task to design such a soapbox. At this time the students get some information about the car (e.g. it should be a single-seater, an Eco-car, etc.) but they get no information about the materials, which they later have to use to build the car. Students should analyse the situation and take into account these lack of information. The second day is used to build the car with the given materials. In this way the students get a first look into practical use of the theoretical mediated content during the lecture.

However, to accomplish a second and improved learning cycle, we extend this scenario in the summer term 2011 with another cost-effective simulation game. In contrast to the support intensive two-day block tutorial (each group gets two own tutors and more supervisors are necessary), we use an online simulation game based on our framework for three weeks. This online game is round based and each round represents one day. Therefore each participating student has to login each day and execute his or her moves. The game is played in groups of five persons, which represents one organization. Each organization is in competition to each other. The content of the simulation game is about a physics project at the European Organization for Nuclear Research (CERN). The game starts with a present-event where the students get an introduction to and the story of the game. This event is followed by the registration phase, a pre-test phase for evaluation of the new game (an online questionnaire), the real gaming phase, and an ex post evaluation (see Fig. 2). In the subsequent two-day simulation game the results of the online simulation game will be addressed and initiate a second learning cycle. This will intensify the mental models. Thus new experiences and the use of the mental model result in a model of action, which is utilized during the two-day course.

5 Conclusion

Students' behaviour and use of technology have changed over the past three decades. Growing up with modern ICT made that technology quite ubiquitous for this generation called Digital Natives. To enable an effective learning experience in higher education and meet the demands of the industry for new employees, we have presented a concept to integrate real life and Internet-based simulation games in higher education. Our concept supports the double cycle of action and reflection and helps to build up and improve mental models regarding to the taught content of a lecture. The simulation game is based on a framework that makes it possible to reuse basic functionalities in different lectures and with different contents.

We continue our research on quantitative and qualitative evaluations to measure the outcome of such concepts for students. On the one hand these evaluations have to consider the learning success regarding to final exams. On the other hand they have to measure the outcome of such Internet-based simulation games regarding to the action competences of graduates. Furthermore we will test our approach in other lectures and with different contents. Even though simulation games can be a way to improve teaching in higher education, further research has to be done on how students can develop or learn action competences, which they need for their later work life. How can we design an excellent teaching environment with the means of communicating complex facts, which goes along with the application of it with relevance for later work life?

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Theory of Digital Natives in the Light of Current and Future E-Learning Concepts

Bodo von der Heiden, Stella Fleischer, Anja Richert, Sabina Jeschke

Abstract The digital generation has many names: Net Generation, Generation@ or Digital Natives. The meaning behind these terms is, that the current generation of students is digitally and media literate, technology-savvy and are able to use other learning approaches than former generations. But these topics are discussed controversial and even the cause-effect-relationship is not as clear as it seems. Did the digital generation really have other learning approaches, or do they have only the possibility to live other learning modes? Against this background this article tries to shed some light on this debate. Therefore we use current and future projects performed at RWTH Aachen University to illustrate the relevance, value and significance due to the theory of the digital natives.

Key words: Digital Natives, Net Generation, Web 2.0 Knowledge Map, Simulation Games

1 Introduction

The digital generation has many names: Net Generation, Generation@ or Digital Natives. The meaning behind these terms is, that the current generation of students is digitally and media literate, technology-savvy and are able to use other learning approaches than former generations.

Based on these conceptual and theoretical constructs the Institute Cluster IMA/ZLW & IfU of the RWTH Aachen University does steady research for some years. One of these investigations refers to Web 2.0 applications in the form of a Knowledge Map and is used in an academical setting of a lecture. Another approach encompasses the development of a simulation game portal that will be also used at the RWTH Aachen.

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In this article these approaches will be highlighted namely in the context of Prensky's theory of the Digital Natives and Digital Immigrants. For this purpose we will give an overview about the theory of the Digital Natives and Digital Immigrants. After that we will mirror the theory in the context of our research efforts.

2 Digital Natives in Contrast to Digital Immigrants

2.1 Short Overview About the Digital Generation

They are called Net Generation [TB98], Generation@ [Opa99], the Millenials [HS00], Homo Zappiens [VV06, Vee09] or Digital Natives [Pre01b] and they have in common that they are digitally literate, technology-savvy and appurtenant to a generation which populates the lecture rooms – currently and in future.

Despite may authors support the theory of a current digital generation there are a lot of critical voices. The criticism is inter alia directed at the designation as one generation, the lack of a unique definition and its weak empirical foundation [LBS09]. Nevertheless the following aspects form an integral part in the different approaches and theories mentioned above and other publications:

- First, the digital generation is born after 1980.
- Second, since their early childhood the digital generation is closely connected with and socialized by digital media and information and communication technologies such as TV, video games, computer and later the internet and mobile communication.
- Third, the digital generation has a different learning approach than former generations, e.g. non-linear learning or multi-switching and multi-tasking.

In this article we will focus on Prensky's [Pre01b, Pre01a] notation of the digital generation as Digital Natives. He defines the Digital Natives as "native speakers" of a digital language (ibid. [Pre01b]). However, Prensky has not only considered the younger generation; he has also concentrated on the parental generation, which is not original digital – this generation is named "Digital Immigrants" (ibid.). This dichotomous notation allows us to focus on and to analyze these two different groups in the next chapter.

2.2 Digital Natives und Digital Immigrants[1]

The following remarks will picture the Digital Natives' and Digital Immigrants' specific characteristics in general and their learning modes in particular separately. Therefore the following questions will be answered:

[1] As an alternative notation Schomburg [Sch10] has chosen the terms "Digital Residents" and "Digital Visitors". But the naming with "Digital Native" and "Digital Immigrant" is the mostly used one.

What are the Digital Natives and for what – that means which characteristic properties – talents and abilities this concept stands for? Who are the people which do not fall into this category, and for what reason? What are the Digital Immigrants?

2.2.1 Digital Natives

The term Digital Natives[2] goes back to Mark Prensky [Pre01b, Pre01a]. As mentioned above Digital Natives speak a digital language[3]. In this context a digital language means the "language of computers, video games and the Internet" [Pre01b].

The concept of the Digital Natives implies that todays students are more familiar with new information and communication technology (further: ICT) than former generations. The early and intensive experience with digital technologies affects the ways of learning, working and communication [LBS09].

But as Prensky states this is not only a superficial phenomenon; the intensive use of information and communication technology, the digital input they receive day by day causes a change in thinking patterns of the students today [Pre01b, Pre01a]. This is attributed to the fact that the students socialization today is vastly different from the socialization of their parents – above all due to the technological development.

The Digital Natives were born after 1980.[4] This dating is no coincidence, as it marks the emergence and expansion of information and communication technology and the penetration of those technologies in all social areas and individual spheres of life. The persons born from this period on are related to ICT in a special, a close way and have an in-depth understanding to use digital technologies [Gas09]. The Digital Natives spend a lot of time with digital technologies. This also implies, that digital media has a significant impact on the identity formation and the personal development. Furthermore they are highly connected and prefer acting in networks (keyword: peer-orientation). They manage their contacts digitally, are always available, always online using the internet or recently the mobile phone and smart phones. Students acting in this way have also another, a non-linear handling in searching, producing, evaluating and using information and knowledge [Gas09]. The emergence and the early and increased usage of ICT are also linked with other learning modes, that mean linear learning modes are expanded through non-linear, linked learning modes by using computer-based-, web-based-trainings or blended learning systems [KS08] In this regard visual presentations become more important. Thus, the self-evident use of new digital media in the younger generation causes a changed learning culture and learning behavior [KS08]. As Prensky stresses, one finding is that "[t]hey (Digital Natives, S.F.) prefer games to 'serious' work" [Pre01a], emphasis in original). It is noteworthy that not only the current generation but also former generations are more likely to learn and work with playful elements. So this statement needs to be discussed further down.

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[2] Already in 1997 Don Tapscott has used the term Net Generation resp. Net Kids [TB98].

[3] The question is: What is the digital language?

[4] 2009 Don Tapscott identifies Americans in the age of 11 to 31 as the Net Generation [Tap09].

In this context the proponents of the Digital Native theory ask for fundamentally new didactical-methodical teaching contents and concepts on the ground of a young growing generation with changed learning habits.

2.2.2 Digital Immigrants

The generations who have not grown up with and are not used to digital technologies but take on recent technology applications like email, instant messenger or social networks in both their everyday and working world, are called digital immigrants.

Presky gives some examples to clarify the digital immigrant's peculiarities: "They include printing out your email [...], needing to print out a document written on the computer in order to edit it [...]; and bringing people physically into your office to see an interesting website [...]" [Pre01b].

What makes this group so special is – as with all immigrants – that they gradually adapt the language and the culture of the target society over a shorter or longer, more or less intensive time, but keep a foot in the home culture [NG07, BO04]. In our context, immigrants have to adapt the language of the information society but always retain in the pre-digital age – this is what Prensky [Pre01b] called "digital immigrant accent" (ibid.). The language differences – as Prensky continues – between the Digital Natives and the foreign-language, digital immigrants induce misunderstandings. Especially in educational institution, where Digital Immigrant instructors bounce against a population with "new" interaction, communication and learning methods it becomes obvious. With the dichotomous construction of Digital Natives and Digital Immigrants Prensky criticizes traditional learning methodologies. In this interpretation linear learning modes using a step-by-step logic and lectures are no longer contemporary.

But the main reason to implement digital information and communication technologies in educational institutions should not be the fact of the assignment of a special generation as "Digital Natives" that is believed to have other learning modes. It is rather a value in itself and the expectation of advantages and benefits, it is the opportunity for mobile, time-independent and user oriented learning environments given by innovative technologies.

Thus, ICT is able to optimize current teaching contents to reach a methodological-didactical rearrangement and to keep ready a lot of advantages – for so called Digital Natives at the universities but also for Digital Immigrants.

3 Two E-Learning Tools for Digital Natives

According to the thesis of the Digital Natives, universities are well advised to adjust their educational offerings towards the requirements and needs of this new target group. Within the world-wide research also the Institute Cluster IMA/ZLW & IfU of RWTH Aachen University has answered the call and has developed and implemented new communication and information technologies, such as Web 2.0 applications, in the area of teaching for some years. With digital applications, the IMA/ZLW & IfU is convinced to support the students learning behavior and to improve the academic teaching. Thus, the following chapter presents two applications developed in the Institute Cluster; the first one, a Web 2.0 knowledge map, is used actually in a lecture; the second one, a simulation game portal, is currently under construction and will find the way to the teaching conceptions shortly. Both case studies will be firstly portrayed against the background of the theoretical foundation of Digital Natives and will be discussed secondly with regard to their relevance in academic settings.

3.1 Current: The Web 2.0 Knowledge Map

In 2010 the knowledge map received the "Runner-Up"-Award in the field of blended learning of the International E-Learning Association.

The knowledge map is currently characterized by four main topics. The knowledge map . . .

- . . . is developed for Digital Natives.
- . . . visualizes explicit knowledge in a non-linear way.
- . . . comprises semantically linked content.
- . . . is continuously developed further.

These main topics will be elaborated in the following paragraphs.

Based on the idea of the Digital Natives and was developed in the project WeKnow (2005–2007). This project focused on research for a method to transfer knowledge from experts to members of the "new generation" – the Digital Natives. Here, a web-based knowledge map has been constructed. The basic idea of the knowledge map is to realize a non-linear learning approach by a semantic net. As described in the second paragraph, non-linear learning approaches are definitely relevant for Digital Natives.

Since its implementation, it is used and evaluated in the blended learning concept of the lecture "Computer Science in mechanical engineering" at RWTH Aachen University with more than 1200 students each term. The concept of the lecture contained a traditional lecture, a lecture accompanying exercises (called project task) and additional exam-preparation exercises. The knowledge map is one of the additional provided online-tools. There are also a Wiki called "eClara" and a forum called "Messageboard".

Similar to a map with visualizations of geographical indications as for example the location of cities and countries, the knowledge map visualizes explicit knowledge. Stocks of knowledge are linked together semantically and structured so that individual knowledge profiles of the experts are formed [SBHS06]. To disclose tacit knowledge, i.e. of empirical knowledge of experts the storytelling method was used [SLS01]. This narrative method uses interviews to make tacit knowledge ex-

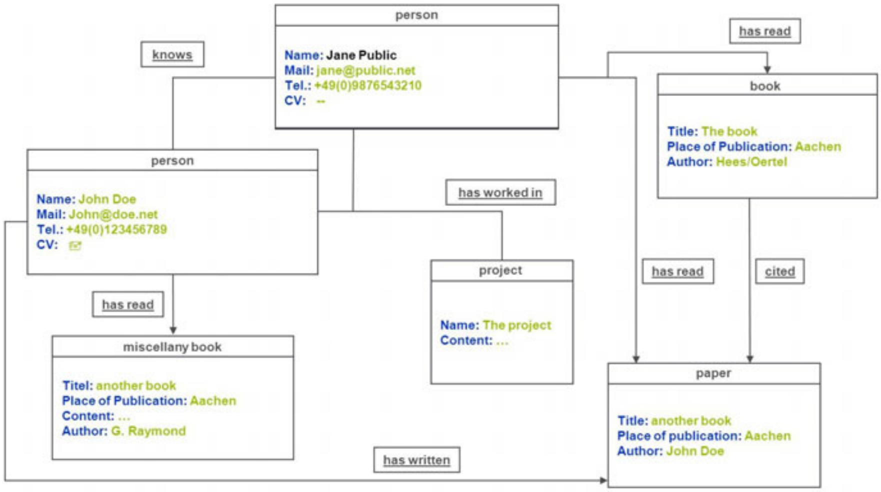

Fig. 1 Snipped of a semantic net

plicit [KR97] which is particularly well suited to document important details and knowledge of experts. Thus, the transfer of process and experience-based expertise in-depth, scientifically knowledge is possible.

Course contents are semantically linked allowing the learners to "browse" through related content. In addition, the teachers, including contact details as a contact person and experts are represented inside the semantic net for certain teaching areas. Figure 1 shows a portion of the structure of the knowledge map underlying semantic network in the university use.

Currently, the knowledge map is developed in the EU-founded project "Responsive Open Learning Environments" (ROLE, 2009–2013). In this project, the knowledge map is transformed from a standalone tool into a learning environment composed with different "Widgets", like a chat- and a history-widget. Widgets are important components of modern graphical user interfaces. The widgets are small programs with different functions provided by different websites. The user is able to select and arranged them individually.

3.1.1 Main Results of the Usage of the *Web 2.0 Knowledge Map*

The user group of the knowledge map in the context of the lecture computer science in mechanical engineering is currently relative homogeneous, but relating their gender and (due to the change to Bachelor/Master-System with many new graduates) field of study it seems that the group is going more heterogeneous in future. From the homogeneity of the group we can consider these students as one group. This fact is helpful for every implementation of new tools. They are mostly male and on average between 20 and 22 years old (in 2010: 89.08 %). The students are in the first or second semester (in 2010: 90.53 %) and study almost exclusively mechanical engineering. One possible explanation for the high proportion of men in the user group is provided by Schulmeister [Sch08]. He noticed that during childhood and youth men are more likely to use technical devices measured by the usage of video games, Gameboy and computer. It can therefore be deducted that the user group is probable highly technology-savvy and is suitable into the group of Digital Natives.

One main result of the survey at the end of each summer term is that the user group often uses pictures, video and audio files and animation in the context of the knowledge map. This supports the thesis that as described above Digital Natives often uses visual and auditory content. Furthermore the students answer that the usage of the knowledge map supports their dealing with e-learning tools as well as networking and – wherefore it is used – discipline-specific content. This shows that a lot of students use online tools for networking and subject-specific learning contents and recognize the benefits.

A significant amount of students have pleaded for various modifications of the knowledge map in different dimensions. Concerning the content the students want more simple examples, pictures and animations. Concerning the conception of the knowledge map the students animate us to look for more personalization of the knowledge map. This confirms the thesis that the new generation (Digital Natives) like visual and animated content for learning. But the requirement of such elements needs to be investigated in further research studies. We take into account this last mentioned request of the students by participation the EU-project ROLE where new techniques for those "Responsive Open Learning Environments" will be developed and tested.

One remarkable finding is that several learning channels and information structures are used. Beside the digital media, like the RWTH Aachen University learning portal L2P and other internet-sites (Google, Wikipedia, Wolfram Alpha, etc.) also traditional learning materials like books, scripts, a pen and an eraser are used. This finding suggests a coexistence of different learning models; the assumed homogeneity of the Digital Natives bears traditional traits and reveals more heterogeneous elements than one might expect at the first glance.

3.2 Prospective: RWTH Academic Simulation Game Portal (ASiGo)

The current critic of the "German Chamber of Industry and Commerce" (DIHK) displays that the education of German universities is too theoretical [Hei11]. According to the underlying questionnaire the main reason for layoffs inside the trial period is the inadequate implementation of technical knowledge into business practice. In the context of the German excellence initiative it is the duty of RWTH Aachen University to convey more practical teaching experience. One approach to improve the situation is the development of a new portal for simulation games. The objective of this project is to support and to intensify the theoretical content of different lectures by simulated practical experiences. Other objectives are to strength on the competence in the students' group- and project-work and to make task roles and problem-solving strategies tangible for them. Students should also learn to recognize of interdependencies of complex communication processes.

RWTH University will use the new portal with a simulation game for the lecture "project management for physicists" in the summer term 2011. The structure of the game follows the structure of two previously developed simulation games called "Q-Key" [Haf00] and "Micro-Key" [Nuß04]. These two games are board games and are played with five persons in a face-to-face situation.

As the students who are listening to the lecture are "Digital Natives", to use a web-based portal is a good approach to transfer the theoretical content into simulated practical experiences. Furthermore the students will learn to work together in virtual groups. This includes that they learn more about the dynamic of groups especially of virtual groups. Hereby the students learn to manage projects where no face-to-face communication is possible and necessary. The simulation game makes it possible to simulate working and situations detached from time, space and face-to-fact-interaction. The students which should use the simulation game additional to the lecture have the option to call a planned or spontaneous (virtual) meeting.

Furthermore the students learn to work in virtual working environments where they must cooperate in a virtual way, like using email, Instant Messaging, etc. oriented towards the ruse of this specific stetting. Through this the students learn to use – so far used private – communication tools in a simulated working area.

Another aspect is that in a real and concrete project no one is able to overlook the whole project with its high complexity in all details. In a face-to-face board based game it is not possible to simulate the complexity and contingency. This is caused by the conceptual model of a broad game where for each team member a situation is pictured on one board. In this respect the simulated online game is a more realistic portrayal of the complex situation in that project management takes place.

Due to the experiences from the surveys of the knowledge map a new platform should not be developed especially for the Digital Natives, because not all users born after 1980 are familiar with ICT on the same level. Thus ASiGo provides learn chances for Digital Natives and Digital Immigrants. Digital Immigrants can – beside the mediated content – e.g. train their usage of modern information and communication techniques – skills which are highly appreciated and in great demand. Since several years simulation games are used to teach practical experiences in a protected environment, to promote cross-linked, integrated thinking and a more practical dealing with complex problems [HvdO08]. These traditional targets of simulation games are also targets of ASiGo. Even the field of adult education and training offers many links, e.g. when setting up a business or with regard to further education on distance universities.

4 Outlook and Summary

The remarks above show two things very clearly: Firstly, the dichotomous usage of the designations Digital Native or Digital Immigrant has some difficulties ready in its exclusivity. This dichotomy is useful with regard to analytical proposes, e.g. to develop new teaching or learning concepts. But one has to consider that is does not mirror the reality. Secondly within and between these two groups various nuances are probable. For the Digital Natives this is verified by the described research results as well as those of other authors [LBS09]. For the Digital Immigrants further, especially empirical research is needed. By developing new learning concepts the heterogeneity of these groups has to be taken into account.

As the results depicts within the Digital Natives non-linear and linear learning modes coexist. This is also verified by other authors [LBS09]. The addition of non-linear to linear learning modes is related to new opportunities given by digital media.

Another aspect refers to the knowledge concerning the usage of digital media. It is known from the literature [Sch08, LBS09] that many Digital Natives do not have the digital and technological background knowledge. Furthermore it is not certain whether a "digital language" really exists. It is also questionable whether it is necessary to speak this language or whether it is sufficient to understand the language. The latter seems to be the case. Both the existence and nature of a digital language and the relationship between technological background knowledge and pure application know how deserves a closer attention.

A further important aspect aims at the process of identity formation [HS07]. Digital media play a not to be underestimated role in the formation of the (juvenile) self. There are allegations that Digital Natives have at least one real identity and one online identity [Gas09]. But the relationship between potential online and "offline" identities have not been supported enough by research at all.

Moreover playful elements in learning and working settings are relatively old. In western societies games (chess) exists since 800 before Christ [Kna04]. So it is most likely that games have always been playing an important role at least in a learning context and not only since the emergency of the Digital Natives. This does not preclude implementing more playful (and digital) elements in learning and working environments.

With regard to the vision of lifelong learning [KS08] digital learning methods like e-learning concepts are attractive for both Digital Natives and Digital Immigrants. Because lifelong learning goes beyond the school career, studies and education approaches and solutions are necessary. Innovative and digital learning applications pave the way for a competitive and well educated knowledge society.

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Übertragbarkeit brettbasierter Planspiele ins Internet

Eine Umsetzung

Bodo von der Heiden, Thilo Münstermann, Sabina Jeschke

Zusammenfassung Der Artikel diskutiert die Potenziale und Probleme, die sich durch eine Umsetzung bereits vorhandener brettorientierter Planspiele in eine über das Internet spielbare Form ergeben. Hierbei werden verschiedene Planspielarten verglichen, zwei konkrete brettorientierte Planspiele, *Q-Key* (Qualitätsverbesserung in Unternehmen) und *Micro-Key* (Verbesserung der Zusammenarbeit von Mikro-Unternehmern), besprochen und analysiert, sowie anschließend eine Möglichkeit aufgezeigt, diese online innerhalb eines Webportals zu spielen. Im Anschluss an eine Diskussion auftretender Probleme und ihrer Lösungsmöglichkeiten wird eine Umsetzung eines Planspielportals vorgestellt. Abschließend wird auf erste Evaluationsergebnisse eingegangen, sowie ein Ausblick auf weitere Entwicklungen und weiteren Forschungsbedarf gegeben.

Schlüsselwörter: Online-Planspiel, Q-Key, Micro-Key

1 Motivation

Das komplexes Denken zu den Schlüsselqualifikationen gehört ist lange bekannt, so sagt beispielsweise Graf, dass „komplexes Denken [...] zu den Schlüsselqualifikationen der Zukunft“ [Gra92] gehört. Eine Möglichkeit, komplexes Denken zu fördern und gleichzeitig „träges Wissen, d. h. Wissen, das zwar theoretisch beherrscht wird, jedoch in einer konkreten Anwendungssituation nicht aktiviert, werden kann“ [SM03] zu aktivieren, stellen Planspiele dar. Planspiele haben das Ziel, das Lernen von theoretischem Wissen mit Aktivität einerseits und mit dem Spaß am Spiel andererseits zu verbinden [Hei92]. Am Institut für Unternehmenskybernetik

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wurden daher in den vergangenen Jahren zwei brettbasierte Planspiele, *Q-Key* und *Micro-Key* entwickelt und in Unternehmen erfolgreich eingesetzt.

Herkömmliche brettorientierte Planspiele sind durch ihren langjährigen Einsatz erprobt. Sie bieten einen persönlichen Kontakt der Spieler, sind jedoch meist nur mit relativ wenigen Personen gleichzeitig spielbar. Die Kosten für die Durchführung jeder einzelnen Spielrunde bleiben, für den Seminarveranstalter und somit auch für den Kunden, jeweils für eine bestimmte Anzahl an Spielern konstant. An diesem Punkt versucht beispielsweise von der Heiden [vdH08] durch die Entwicklung eines webbasierten Planspielportals für Spiele mit einem ähnlichen Spielkonzept wie *Q-Key* und *Micro-Key* anzusetzen. Mandl und Geier (in [Blö08]) beschreiben weitere Online-Planspielumgebungen. Das angestrebte „Effizienzziel" [Hög01] bei der Durchführung von Planspielen beinhaltet vor allem Kosteneinsparung bei gleichbleibendem Lernerfolg und gleichzeitig steigender Anzahl der Spieler.

Im universitären Kontext, beispielsweise an der RWTH Aachen, wird durch die Nutzung webbasierter Planspiele überhaupt erst die Möglichkeit geschaffen, diese in Vorlesungen einzusetzen, mit teilweise über 1500 Studierenden pro Semester. Gleichzeitig wird durch die Bereitstellung eines Webportals für Planspiele und die Möglichkeit, hierfür relativ einfach weitere Spiele zu erstellen, die Möglichkeit geschaffen, Planspiele in verschiedenen Vorlesungen und Anwendungsdomänen einzusetzen. Durch den Rückgriff auf die Konzepte bereits vorhandener brettorientierter Planspiele werden bereits gewonnene Erfahrungen genutzt und auf erprobte Konzepte zurückgegriffen.

Als spezielle Herausforderung stellte sich jedoch eine Aussage aus der Entwicklung von Q-Key heraus: „Die Erfahrungen von *Q-Key* haben gezeigt, dass insbesondere die direkte, reale Interaktion der Spielteilnehmer entscheidenden Lerneffekt hervorbringt, die eine virtuelle Interaktion [vermutlich] nicht ersetzen könnte." [HSe03]. Die geforderte direkte, reale Interaktion der Spielteilnehmer ist (zumindest auf den ersten Blick) bei einer webbasierten Umsetzung nicht mehr gegeben. Gleichzeitig macht genau dieser Punkt einen gewissen Spaßfaktor des Planspiels aus. Eine webbasierten Umsetzung, wie sie im Folgenden beschrieben wird, ist folglich nur dann Erfolgreich, wenn darauf geachtet wird, dass dieser Kommunikationsaspekt (und damit der Motivationsfaktor) nicht verloren geht und gleichzeitig ein (evtl. internetgestützter) persönlicher Kontakt der Spielteilnehmer erfolgt.

2 Vergleich von Spielarten

2.1 Brettorientierte Planspiele

Das wohl bekannteste und älteste Brett-Planspiel ist Schach [Kna04], das etwa 800 v. Chr. entstand und ein klassisches Beispiel einer kunstvollen Simulation darstellt [Roh92]. Dem Spiel liegt das Modell einer Schlacht zugrunde, welche von zwei Spielern durch das Bewegen von Spielfiguren, welche klar definierte Wege beschreiten dürfen, geführt wird. Es wird abwechselnd gespielt und die eigene Strategie ggf. im Laufe des Spiels aufgrund des Zuges des Gegenübers angepasst.

Bei modernen brettorientierten Planspielen existiert meist ein Spielleiter, der das Spiel kennt, die Einhaltung der Regeln überwacht und ggf. zusätzlich bestimmte Funktionen innerhalb des Spiels übernimmt. Die Spieler führen nacheinander ihre Aktionen durch. Entscheidungen können meist mit den Mitspielern besprochen und diskutiert werden. Der Hauptvorteil brettorientierter gegenüber webbasierter Planspiele ist die Möglichkeit der direkten Kommunikation, wodurch soziale Aspekte gefördert werden [Gei06]. Als Hauptnachteil werden häufig organisatorische Gesichtspunkte (Terminfindung, etc.) [Ker03] und die hohen Betreuungskosten [Hög01] genannt.

Im weiteren Verlauf werden die Brettspiele *Q-Key* und *Micro-Key* vorgestellt, die als Grundlage für das Planspielportal dienten.

2.1.1 Q-Key

Das von Haferkamp [Haf00] entwickelte und evaluierte brettbasierte Planspiel Q-Key vermittelt den Spielern die Grundlage von Total Quality Management (TQM). Hierbei handelt es sich um eine umfassende Betrachtung einer gesamten Organisation um Qualität dauerhaft zu garantieren. Für Details sei beispielsweise auf Haferkamp [Haf00] verwiesen. Im Folgenden wird vielmehr der generelle Aufbau des Spiels und den Ablauf einer Spielrunde eingegangen.

Das Spielbrett von *Q-Key* ist in Abb. 1 dargestellt. Fünf Abteilungen (Beschaffung, Produktion, Entwicklung/Konstruktion, Marketing/Service und Versandt/Vertrieb) bestehen jeweils aus 14 Feldern (plus Start- und Zielfeld), welche sich aus einem Pool von fünf Spielfeldtypen zusammensetzen. Jede nach Spielfeldtyp werden Ereignisse ausgelöst, welche Kosten oder Gewinne verursachen können. Jede Abteilung erhält ein Startkapital, das vermehrt werden soll. Im Laufe des Spiels können in drei Ebenen verschiedene Jokertypen (Kunden-, Mitarbeiter- und Prozess-Joker) erworben werden, welche den Spieler vor bestimmten Ereignissen schützen können. Ein Spielleiter überwacht die Einhaltung der Regeln sowie die Entwicklung der einzelnen Abteilungen.

Das Spiel wird mit 3 Spielsteinen auf den Eingangsfeldern jeder Abteilung gestartet. Jeder Spielstein stellt hierbei ein Produkt dar. Durch Würfeln wird bestimmt, wer beginnt. Anschließend wird mit zwei Würfeln gewürfelt und jeweils ein Produkt pro Würfel weiterentwickelt, hierbei ist zu beachten, dass nicht zwei unterschiedliche Produkte bewegt werden müssen. Nach jedem Zug wird die Aktion (siehe weiter unten), die zum Feld gehört, durchgeführt. Hat ein Produkt eine Abteilung durchlaufen, wird es an die nächste Abteilung übergeben.

Zur Halbzeit wird vom Spielleiter eine Auswertungsphase eingeschoben, in welcher der bisherige Kapitalverlauf der einzelnen Abteilungen betrachtet wird und Gründe für diesen Verlauf erarbeitet und besprochen werden. In einer weiteren Auswertungsphase am Ende wird der gesamte Kapitalverlauf betrachtet, ausgewertet und gewonnene Erkenntnisse auf die eigene betriebliche Situation übertragen.

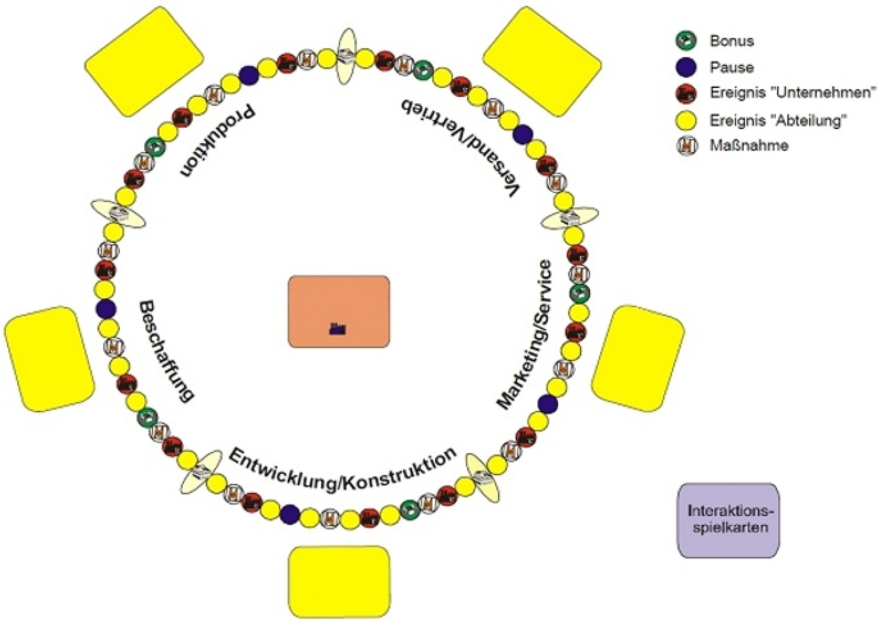

Abb. 1 Spielplan Q-Key [Haf00]

Im Folgenden werden die fünf unterschiedlichen Aktionsfelder (Spielfeldtypen) und ihre Funktionsweise wird kurz erläutert.

- **„Abteilung“:**
  Die oberste Karte wird vom entsprechenden Stapel genommen. Das Ereignis, das die Abteilung oder in Kooperation auch andere Abteilungen betrifft, wird durchgeführt.
  Hierbei gibt es folgende drei Kartentypen:
  - Einfache Ereigniskarten (Ereignisse lassen keine Entscheidungen seitens der Abteilung zu)
  - Einfache Ereigniskarten mit Weitergabe (die Abteilung kann entscheiden, dass das Ereignis an eine bestimmte Abteilung weitergegeben wird)
  - ABC-Karten (die Abteilung hat die Wahl zwischen drei Reaktionsmöglichkeiten, der Spieleiter liest die Folgen der Wahl vor).
- **„Unternehmen“:**
  Wieder wird die oberste Karte vom entsprechenden Stapel genommen. Das Ereignis, das immer alle Abteilungen betrifft, wird durchgeführt. Es existieren passende Joker, die in der Lage sind, eine Abteilung vor bestimmten Ereignissen zu schützen.
  Ein Beispiel für ein entsprechendes Ereignis lautet: "Der Informationsfluss zwischen den Abteilungen ist nicht optimal, so dass viel Zeit verloren geht. Rücken

Sie alle mit zwei Produkten um je 1 Feld zurück! Gegen dieses Ereignis schützt Sie der rote Prozessjoker, der grüne Prozessjoker halbiert die Strafe.".

- **Maßnahmen:**
  Jeder Spieler erhält zu Spielbeginn einen Stapel mit Maßnahmen-Karten. Aus diesen Karten muss er, sobald ein Produkt auf einem Maßnahmenfeld abgesetzt wird, eine auswählen, die darauf beschriebene Maßnahme wird nun laut vorgelesen.
  Eine entsprechende Maßnahme lautet beispielsweise „Sie lassen durch eine Befragung die Kundenanforderungen feststellen.“. Der Spielleiter bestimmt anschließend, anhand eines Maßnahmenschlüssels welche Auswirkungen diese Maßnahme hat.
- **Bonus:**
  Es wird mit zwei Würfeln gewürfelt und die Augenzahl mit einem Faktor (bei Q-Key beispielsweise mit 500) multipliziert. Dieser Betrag wird dann dem Konto des Spielers als Geldeinheiten gutgeschrieben.
- **Pause:**
  Der Spielstein darf in dieser und in der folgenden Runde nicht mehr bewegt werden.

2.1.2 Micro-Key

Bei *Micro-Key* handelt sich um eine Nutzung der bereits bei *Q-Key* erfolgreich eingesetzten grundlegenden Spielidee für die „Unterstützung der Kooperation von Mikrounternehmern“ [HSe03]. Der Aufbau des Spielbrettes ist infolgedessen sehr ähnlich (siehe Abb. 2), lediglich die Benennung der einzelnen Abteilungen und Aktionen wurde geändert. Außerdem kommt eine neue Funktionsweise, das sog. „Learning“, hinzu. Kommt ein Spieler auf das **Learning-Feld**, so erhält der Spieler 500 Geldeinheiten als Bonus, zusätzlich bekommt er eine Erkenntnis zum Thema Kooperation angezeigt/vorgelesen.

2.2 Computergestützte Planspiele

2.2.1 Computergestützte Single-User-Planspiele

Bei Single-User-Planspielen sitzt ein Spieler alleine vor seinem Computer und durchläuft eine gegebene Situation. Diese Art des Planspiels zeichnet sich durch einen relativ geringen Betreuungsaufwand und somit durch relativ geringe Kosten aus. Der Spieler kann Zeitpunkt und Dauer seiner Aktivität frei bestimmen. Das Planspiel kann auf dem Computer des Spielers als Computer Based Training (CBT)-Planspiel oder Internet-basiert als Web-Based-Training (WBT)-Planspiel gespielt werden.

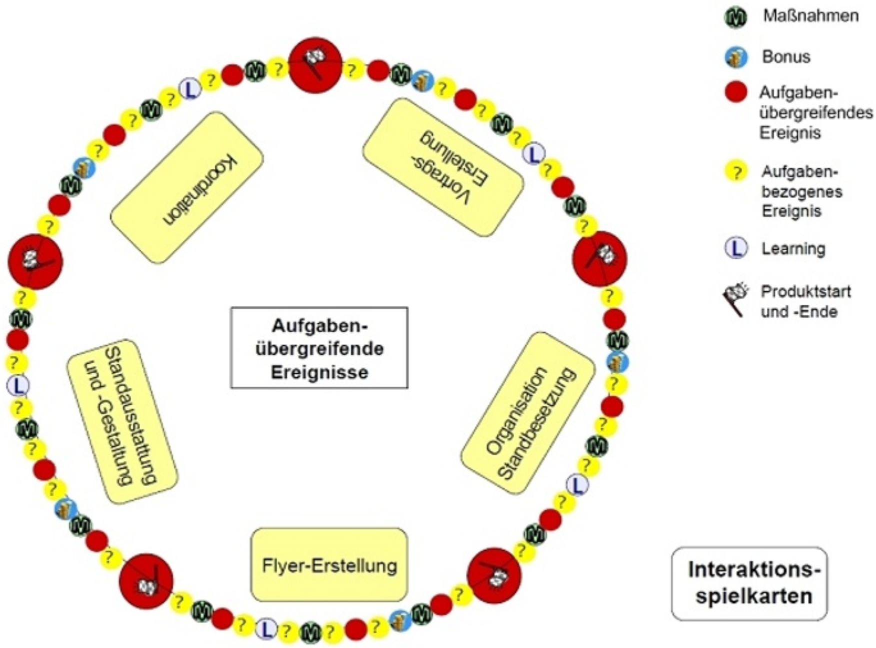

Abb. 2 Spielplan Micro-Key [HSe03]

Durch „die fehlende Betreuung und die starke Fixierung auf den Computer" kann jedoch der sogenannte „Gameboy-Effekt" eintreten [Hög01]. Hierunter versteht man, dass der Spieler z. B. ein Geschäftsjahr immer wieder durchspielt ohne die Hintergründe zu betrachten – um ein möglichst gutes Ergebnis zu erzielen. Ein weiterer Nachteil ist, dass die gesamte Kommunikation und Gruppenarbeit komplett verloren geht, die aber häufig gerade ein wichtiges Ziel von Planspielen. Bei WBT-Planspielen kann eine Kommunikations-Unterstützung (durch Chats, Foren, etc.) geboten werden.

2.2.2 Computergestützte Multi-User-Planspiele

Bei computergestützten Multi-User-Planspielen unterscheidet man verschiedene konkrete Spielformen: Zum einen kann man ein brettorientiertes Spiel, welches zur Unterstützung (zur Simulation) einen Computer benötigt, auch als computergestütztes Multi-User-Planspiel verstehen, zum anderen fallen auch Spiele, in welchen verschiedene Spieler (ähnlich wie an einem Spielbrett) nacheinander ihre Züge an einem (oder im Internet an verschiedenen) Computer(n) machen unter den Begriff der computergestützten Multi-User-Planspiele. Alternativ ist über das Internet auch eine parallele Bearbeitung von Aufgaben möglich.

Gemeinsam ist allen internetgestützten Planspielen, dass mit leistungsfähigen Kommunikations- und Kooperationswerkzeugen versucht wird, die Schwierigkeiten zu kompensieren, die durch das Fehlen direkter Interaktionsmöglichkeiten entstehen. Hierdurch entsteht häufig – quasi als Nebeneffelt – ein Lerneffekt für die Nutzung neuer Medien. Ein Beispiel für ein computergestütztes Multi-User-Planspiel ist das „e-Planspiel" in welchem den Teilnehmern sowohl eine E-Mail-Funktion, als auch eine newsgroupähnliche Pinnwand und eine Chatfunktion zur Verfügung stehen [MRG01, Kel01].

Die unterschiedlichen Kommunikationsformen legen eine weitere Klassifikation computergestützter Multi-User-Planspiele anhand des zeitlichen Ablaufs nahe: Wird zeitgleich (synchron) gespielt, ist eine gemeinsame Terminfindung notwendig. Wird zeitversetzt (asynchron) gespielt, kann der Spieler zwar (in einem gewissen Rahmen) spielen, wann er Zeit und Lust hat, dafür wird die Kommunikation schwieriger. Hieran kann man erkennen, dass eine Abwägung zwischen Vor- und Nachteilen nötig ist, um ein zu dem jeweiligen Einsatzgebiet und Anforderungsprofil passendes Planspiel zu entwickeln.

Ein weiteres Unterscheidungsmerkmal liegt in Definition der "Konkurrenz-Rolle": eine Gruppe spielt entweder gemeinsam gegen andere Gruppen in einer echten Konkurrenzsituation oder gemeinsam gegen den Computer in einer únechten"Konkurrenzsituation. Der Hauptvorteil von unechten Konkurrenzsituationen liegt in einer besseren Vergleichbarkeit von Ergebnissen, nachteilig ist die geringere Motivation der Mitspieler, welche häufig lieber gegen Gegner aus „Fleisch und Blut" spielen [Hög01].

3 Zur Übertragbarkeit von brettorientierten Planspielen ins Internet

Bei der Umsetzung brettorientierter Planspiele ins Internet sind vor allem die Unterschiede der beiden Medien zu beachten. Högsdal [Hög01] schreibt zur Umsetzung brettbasierter Planspielen ins Internet, dass „Diese Vorgehensweise [. . .] sehr skeptisch zu beurteilen [ist], da die Stärke der meisten Brettplanspiele gerade das Haptische und die Interaktion zwischen Teilnehmern ist". Auch Henning und Strina berichten, „dass insbesondere die direkte, reale Interaktion der Spielteilnehmer entscheidenden Lerneffekt hervorbringt, die eine virtuelle Interaktion nicht ersetzen könnte" [HSe03]. Es gilt, die Stärken brettbasierter Umsetzungen mit den Vorteilen einer webbasierten Umsetzung zu kombinieren.

Neben der Abwesenheit des haptischen Empfindens ist ein weiteres Problem, dass viele Internetplanspiele nur eine unzureichende Vor- und Nachbereitung sowie eine unzureichende Erklärungen, welche in brettbasierten Versionen häufig der Spielleiter bietet, während des Spiels bieten. Bei brettorientierten Planspielen übernimmt der Spielleiter meist auch die Aufgabe eines „Erklärers", der für Fragen, sowohl was den Spielablauf, als auch Inhaltlicher Art jederzeit zur Verfügung steht [vdH08].

Fischer [Fis06] schlägt zur Lösung dieses Problems folgende drei Lösungen vor:

- **Integriertes Lernen:**
  Dies ist die wohl am weitesten verbreitete Methode. Sie wird mit dem Ziel verwendet, die Vorteile verschiedener Methoden auszunutzen und deren Nachteile zu reduzieren. Die eigentliche Spielphase wird von Präsensveranstaltungen, in welchen Fragen geklärt werden, begleitet.
- **Ausbau der Kommunikationsmittel:**
  Erleichtert die Kommunikation der Mitspieler untereinander, sowie mit dem Spielleiter. So ist bei aktueller Hardware auch der Einsatz einer Videokonferenz vorstellbar. Ein Nachteil dieser Lösung ist der erhöhte Betreuungsaufwand, welcher beispielsweise beim Internet-Planspiel MINT bereits ab 30 Teilnehmern rund um die Uhr notwendig wurde [Sta01].
- **Einbindung einer Erklärungskomponente:**
  Als wohl technisch anspruchsvollste Lösung beantwortet hier der Computer die Fragen der Lernenden. Dies hat den Vorteil der direkten Rückmeldung, die Hemmschwelle zu Fragen und der Betreuungsaufwand werden gesenkt.

Bei der Umsetzung des Planspielportals wurden die hier vorgeschlagenen Aspekte beachtet. So wird der Einsatz des Planspielportals im universitären Umfeld begleitend zur Vorlesung stattfinden und hierdurch den Aspekt des „Integrierten Lernens“ aufgreifen. Die beiden anderen Aspekte wurden durch den Einsatz einer Foren-Funktion und die Einbindung einer Hilfe-Funktion berücksichtigt.

4 Schwierigkeiten und ihre Lösung

4.1 Verlaufsanalyse – Änderung des Spielkonzepts!

Bei der brettbasierten Version von *Q-Key* und *Micro-Key* handelt es sich um eine serielle Spielweise, d. h. die Spieler ziehen nacheinander (siehe Abb. 3a). Eine solche Spielweise führt dazu, dass nach einem Zug darauf gewartet werden muss, bis alle anderen Mitspieler gezogen haben und man selber wieder an der Reihe ist. Bei einer Umsetzung als webbasierte Version müssten alle Spieler gleichzeitig vor ihren Rechnern sitzen und könnten sich ggf. über einen Chat (ein synchrones Kommunikationsmedium) unterhalten. Alternativ wäre denkbar, dass jeder Spieler per Mail informiert wird, wenn er an der Reihe ist, hierdurch ginge jedoch der Spielfluss verloren.

Ein wichtiger Vorteil einer webbasierten Umsetzung ginge durch ein solches serielles Vorgehen jedoch verloren: Es müsste wieder wie bei einem brettbasierten Spiel ein Termin gefunden werden und die Spieler müssten sich genau zu diesem Zeitpunkt Zeit nehmen. Ein Spiel über Wochen hinweg wäre nicht möglich, wobei sich gerade hierdurch evtl. ein besserer Lerneffekt erzielen ließe, da ein Spieler länger Zeit hätte, über seine Aktionen und deren Auswirkungen nachzudenken.

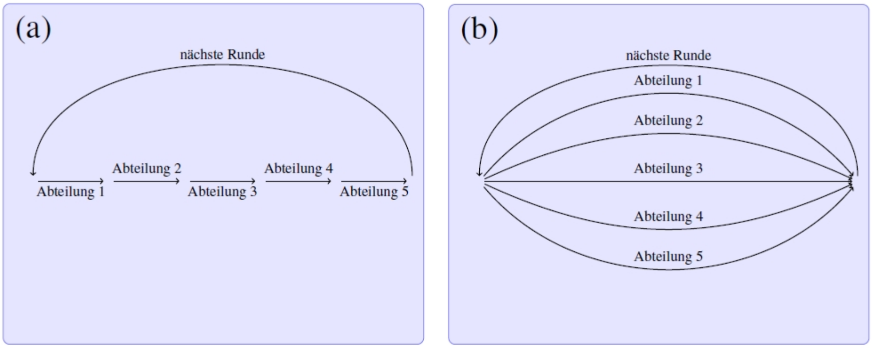

Abb. 3 **a** „Serielle“ Spielweise in der brettbasierten Version; **b** „parallele“ Spielweise der webbasierten Version

Aus dieser Überlegung heraus wurde das Spielsystem bei der Planung des Portals modifiziert. Nun muss zunächst ein Zeitraum festgelegt werden, in welchem ein Spieler eine Runde spielen darf (beispielsweise ein Tag). Innerhalb einer Runde spielen die Spieler parallel, d. h. jeder kann jederzeit seinen Zug durchführen (siehe Abb. 3a). Nur falls ein Interaktionsspiel ansteht, muss ein gemeinsamer Termin (innerhalb des vorgegebenen Zeitrahmens) gefunden werden. Nach jeder Runde wird das Spiel wieder synchronisiert und jeder Spieler, der nicht gespielt hat, wird mit einer Strafe für seine Passivität belegt, die sich im Kapital niederschlägt.

Diese Entscheidung bewirkt, dass zumindest die Spielzüge asynchron stattfinden können. Als Folge dieser Entscheidung wird auf Foren als geeignetes Kommunikationsmittel gesetzt, da auch diese besser asynchron bedient werden können als z. B. (Video-) Chats oder Instant Messenger.

4.2 Ungenaue Formulierungen

Neben der Änderung des Spielkonzepts ist die Umsetzung bisher nur ßprachlich"formulierter Anweisungen in ein starres Regelsystem problematisch. Die Aussage „Gehen Sie 2 Felder zurück“ erscheint beispielsweise klar formuliert, treten in einer brettbasierten Version Unklarheiten auf, so klärt der Spielleiter diese oder die Spieler diskutieren eine Lösung, was die Kommunikation fördert und gleichzeitig zeigt, wie Lösungen gefunden werden können. Bei der beispielhaften Aussage ist unklar, mit welchem Spielstein 2 Felder zurückgegangen werden muss.

Bei einer computergestützten Umsetzung muss eine präzise Formulierung jedoch bereits während der Implementierung festgelegt werden. Aufbauend auf Erfahrungen und Diskussionen wurden alle problematischen Fälle durchgesprochen und entsprechend umformuliert.

4.3 Übersichtlichkeit

Zunächst aus Überlegungen zur Übersichtlichkeit des Planspielportals heraus entstand die Idee, den Spielern nur den für sie wichtigsten Ausschnitt des Spielfelds zu zeigen. Diese Einschränkung verhindert jedoch, dass jeder Spieler immerzu einen Überblick über das gesamte Spielfeld erhält. Um den Spielern dennoch die Möglichkeit zu geben sich die Spielstände seiner Mitspieler anzusehen wurde eine „Manager"-Ansicht eingeführt. Gleichzeitig erhöht diese Änderung die Realitätsnähe, da auch in realen Situationen meist nicht jederzeit für alle Beteiligten ein Gesamtüberblick existiert.

5 Das Planspielportal

Im Anschluss an eine genaue Analyse inkl. der bereits angesprochenen Probleme wurde ein Webportal für Planspiele implementiert, für das sich mit Hilfe von XML-Dateien weitere Planspiele erstellen lassen. Umgesetzt wurde im ersten Schritt eine Variante des brettbasierten Planspiels *Q-Key*.

Das Portal bietet folgende drei unterschiedliche Arten von Benutzerzugängen:

- **Administrator:** Verwaltet, erstellt und fügt ggf. neue Spiele in das Portal ein.
- **Spielleiter:** Betreut ein spezielles Spiel, beantwortet in diesem, bspw. über das Forum, Fragen, ist für alles Organisatorische verantwortlich und übernimmt somit in gewisser Weise alle nicht implementierbaren Aufgaben eines Spielleiters in einer brettbasierten Version.
- **Spieler:** Kann jederzeit auf das Portal zugreifen, sich über das Forum mit anderen Spielern oder auch nur den Mitgliedern seiner Gruppe austauschen und seine Spielzüge tätigen.

Abbildung 4 zeigt die sogenannte „Manager"-Ansicht des Portals. Der Grundgedanke des Layouts besteht darin die Übersichtlichkeit intuitiv und so die Usability hoch zu halten. Aus diesem Grund wurde die Seite viergeteilt, im oberen Teil sind die wichtigsten Informationen (aktueller Kapitalstand, aktuelle Joker, Abteilungsname), sowie Funktionen (LogOut und Link zur Anleitung) angeordnet (im Bild mit der umrandeten „1" markiert). Direkt darunter folgt die Hauptnavigation, in welcher horizontal angeordnet die Navigationspunkte angeordnet sind („2").

Hieran angeschlossen folgt als wichtigster Teil des Portals die eigentliche Spieloberfläche („3"), die sich durch die gewählte Anordnung in etwa in der oberen Bildschirmmitte befindet und so im Fokus der Aufmerksamkeit liegt. Im unteren Bildschirmbereich befinden sich weitere Informationen, welche je nach ausgewähltem Menüpunkt variieren, die oberen drei Bereiche bleiben bei jedem Menüpunkt erhalten und so ständig im Fokus des Spielers.

Wie in der Hauptnavigation zu sehen gibt es zwei verschiedene Foren. Zum einen das „Unternehmens-Forum" und zum anderen das „Spiel-Forum". Ersteres ermöglicht es den Spielern nur mit den Mitspielern ihres Unternehmens, d. h. ihrer Gruppe

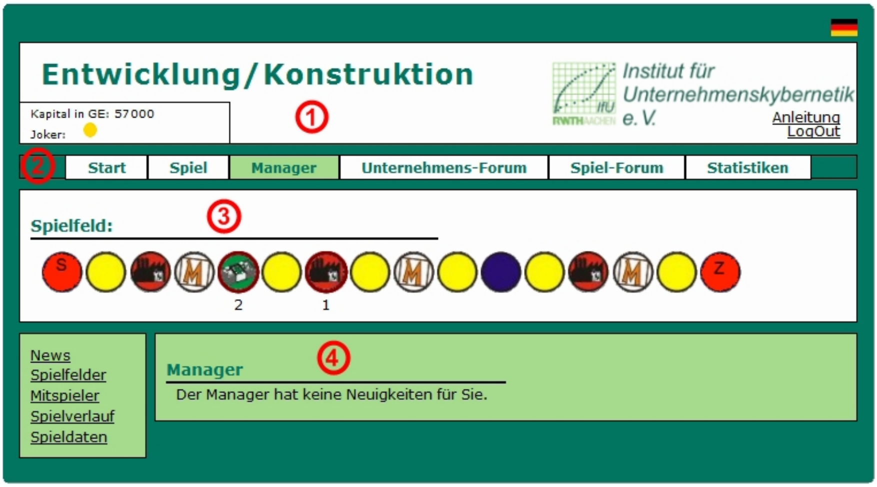

Abb. 4 Screenshot der *Q-Key*-Umsetzung innerhalb des Planspiel-Portals (Ansicht des Managers)

zu kommunizieren. Letzteres dient der Kommunikation aller Teilnehmer. Hier können z. B. generelle Fragen an den Spielleiter gestellt oder organisatorische Fragen diskutiert werden.

6 Evaluation

6.1 Auswertung

Bisher wurde das Planspielportal in zwei Durchläufen in Kleingruppen evaluiert. Ein großflächiger Einsatz inkl. Evaluierung ist für das kommende Jahr geplant. Im Folgenden wird daher kurz auf die bereits verfügbaren Evaluationsergebnisse eingegangen.

In den Probedurchläufen wurde mithilfe einer angepassten Version des BENUTZERFRAGEBOGENS ISONORM 9241/10 von Prümper/Anft [PA06] die Usability des Planspielportals in folgenden sechs verschiedenen Kategorien gestestet [Sch10]:

- Aufgabenangemessenheit: „Ein interaktives System ist aufgabenangemessen, wenn es den Benutzer **unterstützt**, seine Arbeitsaufgabe zu erledigen, d. h., wenn Funktionalität und Dialog auf den charakteristischen Eigenschaften der Arbeitsaufgabe basieren, anstatt auf der zur Aufgabenerledigung eingesetzten Technologie.“
- Selbstbeschreibungsfähigkeit: „Ein Dialog ist in dem Maße selbstbeschreibungsfähig, in dem für den Benutzer zu jeder Zeit **offensichtlich ist**, in welchem Dialog, an welcher Stelle im Dialog er sich befindet, welche Handlungen unternommen werden können und wie diese ausgeführt werden können.“

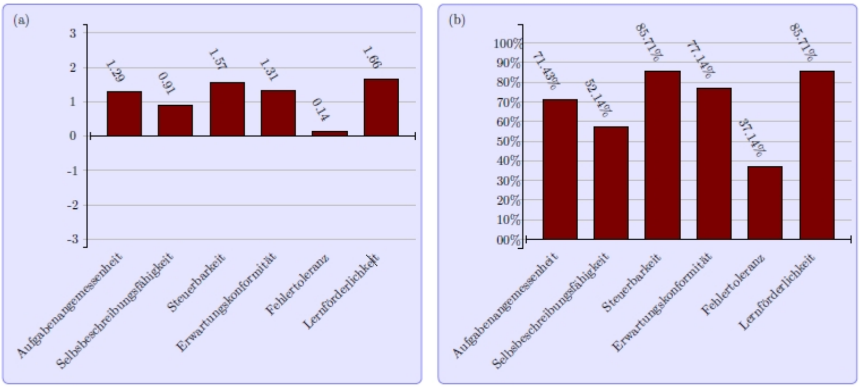

Abb. 5 **a** Balkendiagramm der Ergebnisse des Usability-Fragebogens; **b** Diagramm als Cut Off[1]-Analyse

- Steuerbarkeit: „Ein Dialog ist steuerbar, wenn der Benutzer in der Lage ist, den Dialogablauf zu starten sowie seine Richtung und Geschwindigkeit zu **beeinflussen**, bis das Ziel erreicht ist."
- Erwartungskonformität: „Ein Dialog ist erwartungskonform, wenn er den aus dem Nutzungskontext heraus **vorhersehbaren Benutzerbelangen** sowie allgemein anerkannten **Konventionen entspricht**."
- Fehlertoleranz: „Ein Dialog ist fehlertolerant, wenn das beabsichtigte Arbeitsergebnis **trotz erkennbar fehlerhafter Eingaben** entweder mit keinem oder mit minimalem Korrekturaufwand seitens des Benutzers erreicht werden kann."
- Lernförderlichkeit: „Ein Dialog ist lernförderlich, wenn er den Benutzer beim Erlernen der Nutzung des interaktiven Systems **unterstützt und anleitet**."

Die Ergebnisse sind in Abb. 5 dargestellt.

Gemessen an der Tatsache, dass während der beiden Durchläufe technische Probleme auftraten und die Spieler so unnötig abgelenkt wurden, zeigen die Ergebnisse, dass das Portal durchweg relativ gut bewertet wurde. Lediglich bei der „Fehlertoleranz" gibt es einen Ausschlag nach unten. Zusammen mit einer Auswertung der freien Antworten lässt sich schließen, dass dieses auch auf den Spielcharakter zurückzuführen ist. So wurde angemerkt, dass das Portal „so gestaltet ist, dass kleine Fehler schwerwiegende Folgen haben können".

6.2 Verbesserungsvorschläge der Spieler

In ersten kleinen Test zeigte sich, dass die Unterscheidung zwischen „Spiel-Forum" und „Unternehmens-Forum" den Spielern nicht klar wurde. Über diese wird vor

[1] Bei dieser Analyse wird die Anzahl der positiven Antworten ins Verhältnis zur Gesamtzahl der Antworten gesetzt [Nas07].

einem großflächigen Einsatz erneut nachgedacht. Diese Namensfestlegung erfolgt für jedes Spiel und ist nicht von Planspielportal vorgegeben.

Einige Spieler merkten an, dass „an die Teilnehmer Reminder geschickt werden [sollten], die die Spieler zum Spielen der Runde auffordern". Eine solche Maßnahme wurde in der Spielentwicklung bereits angedacht, diese jedoch nicht umgesetzt, da eine technische, automatische Lösung zwar daran erinnert, Spielzüge zu machen – für die realitätsnahe Kommunikation im Team ist dies jedoch kontraproduktiv. Ziel ist vielmehr, dass die Spieler ihre Teammitglieder dazu auffordern zu spielen. In Gesprächen zum ersten Probedurchlauf kam heraus, dass hier von einer Spielerin genau diese Funktion übernommen wurde.

Eine offen gehaltene Frage an die Spieler fragte danach, was sie allgemein verbessern würden. Hierbei trat der Wunsch auf, „Diskussion bzw. Strategiesitzungen als festes Element in den Spielablauf" einzubauen. In diese Richtung zielt auch ein weiterer Vorschlag „Es sollte ein Zwang zur Diskussion in das Spiel aufgenommen werden, bisher entsteht die Diskussion eher auf freiwilliger Basis und die Teilnehmer können sich entscheiden, ob sie mit anderen diskutieren oder eher doch alleine agieren.". An dieser Stelle muss ein Konzept entwickelt werden, wie die Spieler in verschiedenen Situationen zur Diskussion angeregt werden können.

7 Ausblick

7.1 Fortschritt der Technik

Die sich durch die Weiterentwicklung des Internets ergebenden sich Möglichkeiten der Integration von neuen synchronen wie asynchronen Kommunikationsformen in Webseiten. Jedoch existieren heutzutage noch Probleme mit bestimmten Kommunikationsformen. So könnte beispielsweise die Einbindung von Video-Chats in Webseiten das Kommunikationsverhalten ändern. Als asynchrone Kommunikationsform wäre das gegenseitige Zusenden von aufgenommenen Videos oder Sprachnachrichten denkbar, ob diese Kommunikationsform allerdings wirklich Vorteile bringt, muss noch wissenschaftlich evaluiert werden. Aktuelle Forschungsergebnisse deuten darauf hin, dass Spiele sogar dazu dienen könnten, die Kommunikationsfähigkeit von Spielern zu schulen [Fra09].

7.2 Forschungsbedarf

In der Literatur werden Umsetzungen brettbasierter Spiele ins Internet meist kritisch betrachtet [Gei06]. Diese Grundannahme wird zwar begründet, diese Begründungen jedoch nicht untersucht. So ist keine Studie bekannt, welche den Einfluss des Kommunikationskanals, also eine Face-to-Face vs. computergestützte Kommunikation, auf den Lernerfolg bei Planspielen untersucht, allenfalls ein Zusammenhang zwischen Motivation, durch die Nutzung neuer Kommunikationskanäle, und Lernerfolg wurde festgestellt (vgl. Holzinger 2001).

Die Auswirkungen von Übersichtfunktionen über die Spielfelder sind ebenfalls noch zu untersuchen. Auch ob eine Umstellung einer „seriellen" in eine „parallele" Spielweise einen Einfluss auf den Lernerfolg hat und welche sich besser für Spiele welcher Art eignet ist eine ungeklärte Frage.

Auch die immer weitere Verbreitung von Smartphones, also internet-fähigen Handys, stellt eine Herausforderung der Zukunft dar, da die Gestaltung von Planspielen für solche Geräte mit meist relativ kleinem Bildschirm andere Anforderungen stellt. Hierbei könnte auch die Nutzung von haptischem Feedback, welches laut Högsdal [Hög01] eines der Vorteile von brettbasierten gegenüber webbasierten Planspielen darstellt, beispielsweise durch die die Nutzung des in Handys eingebauten Vibrationsalarms, auf den Lernerfolg untersucht werden.

Wie hier kurz aufgezeigt, besteht gerade was die Entwicklung internetbasierter Planspiele angeht noch ein großer Forschungsbedarf. Auch müssen technische Neuerungen konsequent als Chance begriffen werden, Planspiele und weitere Modelle digitaler Lernspiele bekannter und einer breiteren Masse von Menschen zugänglich zu machen.

Das Planspielportal wird seine Tauglichkeit voraussichtlich im Sommersemester 2011 unter Beweis stellen können. Es ist geplant das Planspielportal im Rahmen der Vorlesung „Projektmanagement für Physiker" an der RWTH Aachen einzusetzen. Da weder *Q-Key* noch *Micro-Key* inhaltlich zu dieser Vorlesung passen, wird zunächst passendes Spiel entwickelt. Das Planspielportal und das Planspiel zum Projektmanagement wird – nach positiver Evaluation während des Sommersemesters – fester Bestandteil der Vorlesung. Die Entwicklung weiterer Planspiele für andere Veranstaltungen ist bereits angedacht.

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Knowledge Management in Vocational Training
A Case Study of the EU Project RELOAD

Florian Welter, Thomas Thiele, Olivier Pfeiffer, Anja Richert, Sabina Jeschke

Abstract The need of diverse businesses to qualify their employees by means of vocational training is in most cases connected with high efforts due to expensive face-to-face courses and downtimes of the employees. Although, the emergence of IT-based knowledge management and e-learning tools led to a broader range of education possibilities during the last years, the fact remained that too many approaches were not user- or learner-centred. Besides, a lot of vocational training approaches did not include modern didactic concepts which foster a self-directed way of learning. Hence a stronger consideration of the interplay of the aspects "human, organisation and technology" – the so called HOT-Approach – can help to overcome this challenge. Referring to this, a successful case study is presented with the EU Project RELOAD in this paper. The focus of the project RELOAD is set on employees of the Do-It-Yourself (DIY) industry in which employees as well as consultants play a decisive role because they communicate directly with end customers during sales and consulting talks. Due to the fact that a lot of employees and consultants in this sector are untrained, low qualified workers, or even workers from other sectors, a tailor-made vocational training is necessary. With regard to this, RELOAD tries to address employees and customers at the same time by offering a knowledge platform as a semantic-based solution. This platform contains e-learning modules enabling the users to actualise their knowledge much more efficient, faster and self-directed than by the use of conventional vocational training approaches. Moreover, this kind of self-directed learning can easily be integrated into dynamic daily work processes and at the same time it is more cost-efficient. As a consequence of the project results, various DIY retailers show interest to use and further develop the

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RELOAD knowledge platform. With regard to this, new ideas and needs for research are elaborated by the project consortium to set up a following-up project in future.

Key words: Knowledge Management, E-Learning, Do-It-Yourself Industry, Microtraining, Semantic Technologies, Knowledge Platform

1 Introduction

Knowledge in terms of an economic factor gains globally an increasing importance. Hence the acceleration of the information- and knowledge-growth as well as change processes in the society require a new understanding of learning and the willingness for a continuous personal education. Furthermore, the growing demands of the information- and knowledge-society require that each individual needs to focus more on self-learning. This means that individuals also have to adapt qualifications and skills independently to the needs of a respective working environment to ensure employability through self responsibility. In a strategic study conducted by the German Federal Ministry for Research and Education in the year 2003, various trends were identified with regard to the education requirements of the future [BMB03]. One of these future trends depicts the fact that (lifelong) relearning will become common [Das00]. Referring to the latter, relearning can be defined as the ability of an individual or a single employee to acquire new knowledge in an independent and self-determined manner with regard to the respective professional background. Hence, relearning is necessary to update knowledge continually and to be able to cope with developments which are relevant for a profession, e.g. the introduction of new technologies or working processes. Additionally, in case of changing framework conditions and working processes it is also important to forget about already acquired professionally-oriented knowledge.

1.1 New Media as an Approach to New Requirements

To meet the increasing demands of the contemporary business world, an increasing learning competence is essential. This means that the individual needs to have the ability to begin a learning process auto didactically and to continue and finish this process successfully. An approach to support these learning processes provides the integration of new media in education. Today the internet constitutes the first source of new information and new knowledge, even in the field of vocational training [Zin05]. According to this, web-based e-learning applications aiming to transfer knowledge can contribute essentially to this development [Mau00]. Nevertheless, it is crucial that the human (respectively the learning individual) as well as didactic concepts may not lag behind the implemented tools of an IT-based knowledge management or e-learning. This means that the broad range of possibilities, which come up through global networking, a fast transfer as well as a location-independent availability of information and knowledge, has to be used in a sensible way. In doing so IT-based knowledge management and e-learning applications can be implemented in a tailor-made manner to help learning individuals to meet the demands of a knowledge-based society.

With regard to the latter a general approach should follow the so called **HOT**-Approach [FS03]:

- First of all it is necessary to identify and to promote the users' abilities, basing upon the respective mental model and the needs of the users (**H**uman).
- Secondly the organisational framework has to be optimised (e.g. learning on the job, learning by doing, learning with formalised education) (**O**rganisation).
- In the third step an inquiry has to be accomplished in how far possibilities of e-learning approaches (and attached technologies) can support the process of relearning (**T**echnology).

Pertinent research results in knowledge management have already proved that just a holistic approach has a sustainable impact and that it is promising to combine it with blended learning approaches [HS04].

1.2 Knowledge Management in Vocational Training: Former and Contemporary Developments

Enterprises have to face the challenge of acquiring new knowledge continuously, especially with regard to restricted resources of small and medium sized enterprises (SME). In how far the actualisation of employees' knowledge can be managed thus constitutes still an unsolved question for various SME. Hence, methods are required which train employees as effective, fast and cheap as possible. At the same time these methods have to be able to cope with a growing knowledge production. Because of that, a huge number of enterprises followed the trend to implement IT-based knowledge management tools and e-learning applications as an answer to these challenges during the 1990s. However, it became apparent that employees in these enterprises did not learn self-directed just because of introduced e-learning applications. One can state that too often it was not the learner who was in the centre of such applications but the technical realisation of the learning contents. Parallel to that the fast technical progress was not accompanied fast enough by the development of adequate pedagogical concepts. Moreover, the majority of e-learning applications are restricted in terms of providing factual knowledge. Although this form of knowledge can be reproduced correctly by methods of knowledge management and e-learning platforms, the utilisation of this knowledge in practice cannot be described as a logical consequence of the reproduction [SM04]. Because of this, a rethinking took place during the last years leading to a shift from technical centred knowledge management and e-learning applications to human or learner centred approaches (including methods and didactic).

With regard to this, especially the integration of e-learning into daily work and self-organized forms of learning becomes more important than classical forms of education. Due to continuously increasing costs and more dynamic working processes it is more difficult to integrate the latter forms into the daily working environment. These new forms of self-directed learning through the help of new media correspond with the theoretical approach of the constructivism. This approach describes learning as an active construction process which is strongly embedded into a social context and which is characterised as a situational process [RM97]. Furthermore, the constructivist consideration of learning processes focuses on self-organisation. As a consequence of this consideration, learning processes can just be stimulated externally (perturbation) but they cannot be transferred into direct knowledge [AS03]. Against this backdrop the basic intention of all supporting measures changes: The measures do not aim at transferring knowledge from one person to another but they provide knowledge resources and learning support in terms of enabling learning [AG07].

1.3 Semantic Technologies as a Solution

Considering the former described development, the key to an effective utilisation of knowledge management and e-learning approaches in vocational training constitutes a sensible networking of the stored information to be able to exploit new knowledge. This means that information only depicts a value for humans when they are able to realise the impact of the respective information in a concrete situation. At this point semantic technologies for knowledge management come into play, because semantics allow the decisive step from information to knowledge [Bei04]. Referring to this it has to be stated that the latter is always embedded into a specific context of action. Thus knowledge is developed throughout a specific situational pattern of information and enables humans to act in a sensible manner (see Fig. 1).

The crucial value of semantic knowledge management applications in the area of vocational training thus can be described with an augmentation of the quality of information. This augmentation happens through demand-oriented networking of information in the context of organisation-specific targets and concrete processes. Due to this kind of networking the employee or learner receives the required contextual information – independent from location and time – which can enable the development of new knowledge [Bei]. Nevertheless, enterprises integrate social software and semantic knowledge management applications only hesitantly in their business environment, maybe because of the fact that business applications have other requirements than applications for private users. Furthermore, the reason for a still limited diffusion of semantic knowledge management solutions can be explained in particular with the costs and efforts of introducing such systems. Hence it is nec-

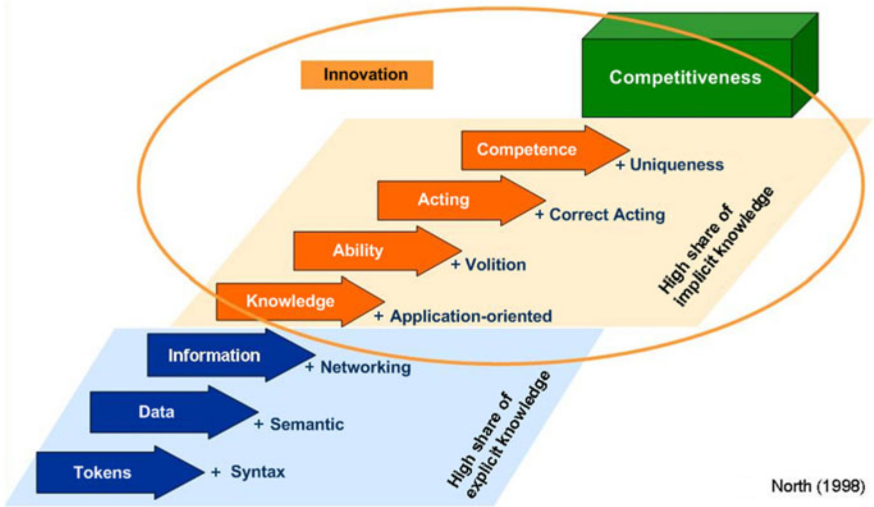

Fig. 1 Steps of Knowledge Development (extended after "Wissenstreppe", North 1998) [Nor98]

essary that the effort of introducing semantic systems has to be compared directly with the benefits originating in an optimised information quality which e.g. cannot be provided by simple search engines. The benefit of the latter just focuses on the fact of saving time while searching for information. In comparison to that semantics make information easier accessible within work-specific learning processes and because of that they contribute directly to value added.

1.4 Microtrainings as a Didactic Solution

Concerning the human perspective of the HOT-Approach the emergence of new self-directed learning concepts can be stated during the last years, which are also promising for various businesses in combination with semantic technologies. With the approach of so called Microtrainings (which aim to train learners in a short period of time) such a promising concept shall be described in the following section.

A typical Microtraining unit is characterised by a duration of approximately 15 to 30 minutes. The relatively short time is important with regard to the target group e.g. consisting of people who work in fixed shifts or on location such as production staff, installers, builders, sales people etc., from which at least some would lose interest or would be overstrained by longer learning units. Thus, each unit begins with a short activation of the participants by introducing them into the topic and by pointing out the target of the unit. Furthermore, a short (multimedia) demonstration or exercise is given to introduce every participant into the topic. E.g. this can be done with a video and a short exercise about technical details of a tool or details of a service process. These first sections are followed by a phase of discussion and feedback in which questions to different items, products or processes are posed to stimulate the group of learners to actively share their (tacit) knowledge. Especially with help of the questions it becomes possible to control if the input was understandable for all participants. In the final phase of a Microtraining unit, a short summary of the formerly learned content is provided, underlining the main learning achievements for the users and giving a short preview of further units in order to stimulate interest in visiting following learning units [otEPM10].

Hence it seems to be obvious that the basic idea of Microtrainings – which aims to train people within several minutes – is predestined to combine it with an adequate semantic IT-environment offering the opportunity of a self-directed learning e.g. by providing training units on a web-based platform. In how far such an idea can be put into practice shall be elucidated with the following case study of the EU project RELOAD.

2 The Case Study: A Semantic Based Learning and Knowledge Platform for the DIY-Industry

In the EU founded project RELOAD a multinational consortium of Universities, DIY retailers and branch experts developed a semantic based learning and knowledge platform in order to enhance the vocational training of employees in the DIY industry. This target audience is mainly untrained and less qualified regarding their primary duty as sales assistants by counselling interviews with end customers. Various learning platforms have been developed directly by DIY retailers and they were integrated in already existing vocational workshops, but so far there has been no breakthrough in establishing an e-learning standard in this branch. As one step to enable this standard, the RELOAD platform was designed under the above-named Human-Organisation-Technology (HOT)-Approach and the principles of the constructivist learning theory.

2.1 Didactical Approach (Human)

The primary aspect of the constructivist learning theory is the self-reliance and self-responsibility of the learner. Comprehension is constructed through reasonable interpretation of information. As an active process interpretation of information is based on the learners' previous knowledge. Since the RELOAD learning platform is designed to cope with the needs of experts and apprentices, the learning process has the requirement to be individual. In order to support the above mentioned interpretation as an active process, the platform presents an interactive environment to the learner to enable the construction of an individual comprehension.

In addition to that, following the constructivist learning theory, the construction of individual knowledge and comprehension requires the exchange between the learners. The enhancement of this exchange is a key element to create a better learning effort. By implementing a method to ensure communication and exchange between the learners the vocational training gets more authentic, meaning that the learning lesson should correspond to the cognitive context and requirements of the learners' working environment [Mie07]. To embed information into a context is another strategy to ensure a better result in the procurement of knowledge. The learner assimilates the information in the context it is presented and therefore gets a deeper understanding of the presented elements. The content of the RELOAD platform has to fulfil the needs and requests of the learners. Therefore it has not only to answer daily questions with which an employee in the DIY branch has to cope with, but also to distribute practice oriented information, which enables the employee not only to sell an item, but to guide the customers in their projects.

One of the main disadvantages of a classical vocational workshop is the cost for a workshop. The employer does not only have to pay the workshop, but also has to bridge the downtime of the employees. In the learning environment of the RELOAD platform this problem was addressed by using a learning-on-the-job model.

The learning scenarios of the learning-on-the-job platform differ from standard applications. For the DIY branch it is typical that only a few employees use personal computers in their daily working routine and therefore they have no easy access to the learning platform. As a result most employees are not experienced in the use of personal computers and must leave the sales room to use the platform in a computer room. Although this might be a disadvantage, a separate computer room creates a better environment for a concentrated and undisturbed learning process. Hence, to support the individual learning in a typical learning scenario the platform offers different approaches for the learner to entry a lesson. Selected scenarios shall be described by the examples:

- "Guided Tours"
- "Product Finder"
- and "Application House" (see Fig. 3).

The "Guided Tours" compensate the lack of tutorial support during a lesson. Especially designed for apprentices this tours offer guidance in typical customer problems and projects. Advanced learners may start directly into a lesson and may skip certain steps.

Beside the "Guided Tours", learners can enter the platform through a lexicon. Rather the access for advanced learners, the lexicon lists all topics in alphabetical order. Especially designed to distribute knowledge in the field of product characteristics the "Product Finder" specifies power tools dependant on different criteria. These criteria are based on typical customer claims.

Fig. 2 The start-up screen of the RELOAD learning platform, listing various entries for the learning scenarios

The entry "Application House" is a project based approach. In the range of characteristic activities around preliminary building works, house development and renovation the user can virtually move to different rooms and areas in a house and select learning lessons in the context of the room. For example, if the user hits the parquet lined living room, one of the units offered in the renovation modus is "floor polishing".

The "Anchored Instruction" principle focuses on the anchoring of content by motivating and meaningful episodes. In doing, so previous knowledge is activated aiming at an active learning process. Incorporating know-how and operating experience, interest and intrinsic motivation advances as well as the development of inactive knowledge is reduced. Although demanding a multimedia based learning platform and therefore raising the deployment complexity, this use of media creates an environment of self-directed learning towards new abilities and skills. Supplemental to the "Anchored Instruction" the "Cognitive Apprenticeship" is implemented to ensure the transfer of practice oriented intercession principles to the handling of complex problems. As the didactical basis for the structure of a learning lesson these two approaches form the framework for the concrete elaboration of Microtrainings in RELOAD.

Fig. 3 The RELOAD "Application House" (Blue boxes indicate learning lessons – here in the field of renovation)

2.2 Knowledge Model (Organisation)

Due to the fact that RELOAD constitutes a project within the "Lifelong Learning Programme 2007–2013" (Leonardo da Vinci) of the European Union, the intention of the project was to transfer innovations into practice. Thus, an adequate organisational framework was considered which based on the learning on the job concept. Concerning the latter the consortium agreed in the decision to realise the concept by the implementation of Microtrainings.

As mentioned in Sect. 1.4 Microtrainings are short, group based learning lessons following the general structure in Fig. 4. Due to the short duration the learner focuses on the given task and the downtime of the personal is minimal.

Regarding the requirements of the didactical concept of

- an interactive environment to construct individual comprehension,
- exchange between the learners,
- learning on the job and
- reduced costs.

Microtrainings are a suitable organisational form for the learning sessions. For the needs of RELOAD the already short duration of 15 to 30 minutes is decreased down to 5 to 15 minutes due to a target audience, which is not familiar with learn-

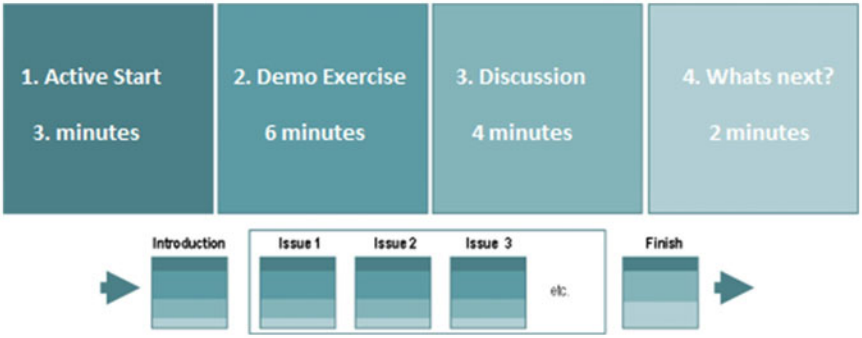

Fig. 4 General structure of a Microtraining unit [otEPM10]

ing. Daily problems resulting from customer counselling serve as a narrative anchor for the learner and therefore as active start for the Microtraining. The demo exercise of the session can easily be realised by a multimedia platform. Manufacturers of the DIY industry integrated their instruction documentation, formerly used in vocational workshops, into the platform resulting in higher cost effectiveness for the manufacturers and the retailers. Considering the multimedia character of the RELOAD platform pictures, video-simulations and documents can be stored as a demo exercise. Subsequent to the exercise the leaner is invited to practice the acquired knowledge and therefore internalise the presented information. Supported by a dialogical structure of the platform the user gets more and more used to self-directed learning. The Microtrainings are divided into sections of different content and difficulty. Thus it is assured that learners with different vocational background can choose topics according to their level of knowledge. As another side-effect a large flexibility of knowledge acquisition is offered. As a third step of the Microtraining the following discussion is enabled through a feedback. The users are encouraged to comment the content as well as the offered media. The operator company is thereby in the position to identify possible weaknesses in the contents of the RELOAD platform. The "What's next?" step of the lesson is an integral part to embed the content into a greater coherence and thus to realise the authenticity and practice relevance of the learning unit.

The content of a Microtraining unit meets the requirements of a counselling interview. The first step of a lesson imparts product knowledge. After a short test to ensure the sustainability of the information a chapter on "how to utilise the product" follows. The last part of the lesson trains selling knowledge and is based on the previous fundamentals. This structure assures that the user not only obtains all necessary information to support the projects of potential customers, but also learns how to organise a counselling interview.

Following the above mentioned didactical model embedding information into a context is a key strategy to create authenticity and sustainability of knowledge. In

RELOAD most lessons are connected through a Semantic Net. By intelligent and non-linear connections it is ensured that further links are offered, which lead the user to new topics and encourage the construction of new mental associations between different areas in the DIY branch. For example, if a user looks up the lesson "How to tile a Bathroom?", an additional reference leads to the installation of a basin. Thus the user learns to think of complete projects and therefore gains the ability to provide advice not mentioned by the customer. Since the Semantic Net as organisational form of the knowledge supports the ideas of the didactical concept, the technical realisation is the next step in the HOT approach.

2.3 The Realisation of RELOAD (Technology)

Concerning the technical realisation of RELOAD a web-based approach is implemented to enable a broad accessibility for various users. Hence the web-based approach allows a time- and space-independent access and offers parallel to that a design in the style of common websites. Because of this, the users of the knowledge platform are trained in the utilisation of new media, too.

The basic concept of the RELOAD platform is a relational database. Not only this technology ensures great flexibility and an easy-to-use administration, but it is also a practicable basement for the implementation of the Semantic Net and as an authentic learning environment. Mainly based on linked spreadsheets the contained data can be easily connected and combined. By the rules of relational algebra a mathematical description was developed in order to define distinct rules and operators [Cod70]. By using these features the database becomes flexible and can be (re-)organised according to the wishes of the user. As a key element for the successful implementation of the Microtrainings this individual storage and arrangement capability meets exactly the requirements of the constructivist learning theory, mentioned in Sect. 1.1. Through its individuality the system creates a non-static learning situation, which can offer different approaches to the stored contents. Thus the user can choose the right way for him to learn. Another advantage, this system offers, lies in the customisation capability of the database. As the assortment of goods varies, each local supervisor can readjust the contents to fit the distinct alignment of his products.

As mentioned in previous sections the Semantic Net logically and didactical reasonably connects the entries of the platform. At the end of each learning session a so called "link-box" offers associative related topics with the aim to encourage the further learning process. The content of the "link-box" is automatically generated by meta data, which is implemented into the relational database. This meta data is based on classes and objects. Classes can be seen as categories for the products and therefore structure the content in the above mentioned topics. The objects are specifications of these categories and real entities, in the case of RELOAD typical products of the DIY branch. Both classes and objects form key attributes of the meta data used to form the relations of the Semantic Net.

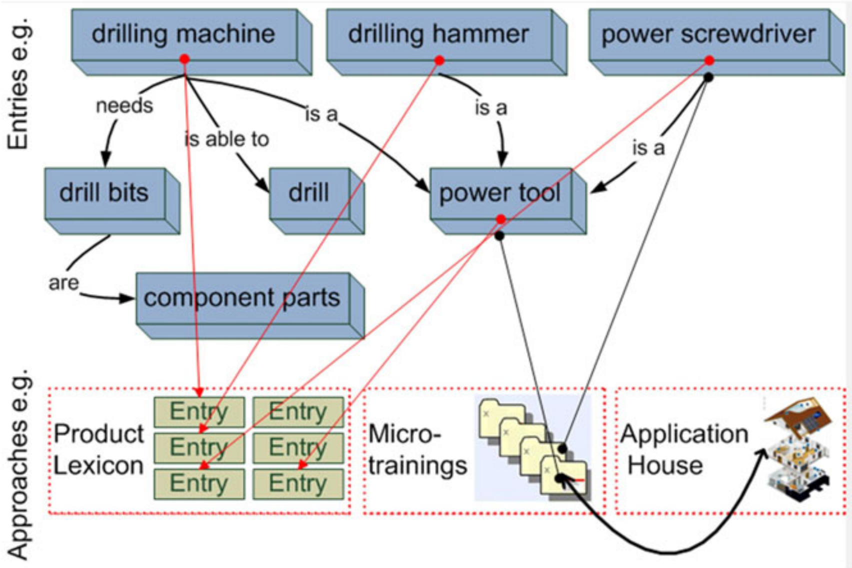

Fig. 5 Extract of the Semantic Net used in the RELOAD platform

Based on MY-SQL and ZOPE objects the Semantic Net implements a personal learning path through the content of the platform. Tracked on a "personal learning desk" this technology enables the retracing of the learning process and therefore supports the idea of a self-determined learning process by visualising already started and completed training units. As the Semantic Nets connects all entries of the RELOAD platform different types of connections have to be created because of the various approaches noted above (see Fig. 5).

As a primary technology to incorporate new Microtrainings into the RELOAD platform, a template has been developed. Based on Microsoft's Power Point this interface is available to most content creators and demands little practising time, but also supports the multimedia approach of the platform.

3 Results and Concluding Remarks

With regard to the introduction of new learning approaches in vocational training huge efforts were undertaken by enterprises as well as universities in the last decades. Still one of the main challenges can be described with providing a low cost vocational training approach which motivates employees to use it in a self-directed way. Thus, contemporary developments in knowledge management and e-learning focus more on a human centred design than in the last years in which technology centred designs prevailed. Since a closer integration of new didactical concepts with adequate knowledge management and e-learning tools takes place nowadays, advantages become obvious e.g. through the stimulation of a self-directed learning among various groups of employees.

Furthermore, the introduced case study of the EU-funded project RELOAD highlighted a successful advance in the field of vocational training. Because of the fact that the so called HOT-Approach (**H**uman, **O**rganisation and **T**echnology) was considered during the entire project runtime, requirements on different levels were analysed to create a holistic vocational training that can be applied in the DIY-Industry. Hence, the main innovations of RELOAD can be characterised with the integration of Microtrainings as a special didactical form and the use of semantic technologies as a non linear form of knowledge management. Due to the fact that many employees and consultants in DIY stores are untrained, low qualified or even workers from outside the sector, the integration of Microtrainings and semantic technologies in RELOAD was successful as it is revealed in project internal test runs in the years 2008 and 2009.

Through the results of the test phases in the participating DIY stores it became obvious that the target group handled the provided applications on the RELOAD knowledge platform in a satisfying manner. Nevertheless, general deficits of the employees in the DIY branch became obvious, too, concerning the general use of personal computers and the familiarity with internet applications. The latter could be underlined by a couple of qualitative user interviews which have been conducted after the test phases by partners of the RELOAD consortium. As a consequence, providing personal trainers (in combination with an individual training schedule) could be another possibility for those employees who are inexperienced in using computer applications. In general, the platform received a positive feedback with regard to the usability of its Microtraining units. Referring to this, one can stress that the use of the Microtraining units seems to be more effective for the employees during their working time (learning on the job) in comparison to complete learning units at home.

Concerning the RELOAD business model various DIY retailers showed interest in a continued use of the knowledge platform in order to reduce the costs of classical vocational courses. With regard to this the commercial supply of e-learning units can be seen as a chance for the RELOAD knowledge platform, although a continuous further development of contents and learning units is necessary to meet the demands of a broad range of retailers.

4 Future Prospects

A next step in future could comprise a certification of the informal learning concept integrated in the RELOAD knowledge platform in order to create a standardised form of vocational training by the use of new media. With regard to this, a further integration of suppliers from the DIY-industry is desirable in future and should be attempted in follow-up projects. Especially a broader range of partners from different European countries could be interesting to develop multilingual learning units which e.g. could provide a standard for different actors of the DIY-industry within the European Union.

Besides, a more standardised concept of the RELOAD knowledge platform could offer in particular small and medium sized enterprises (SME) the opportunity to market their products as well as to edit product information easily into standardised e-learning units. Moreover, the production costs for training materials can be estimated as relatively cheap in comparison to the costs for training sessions which are just performed face-to-face in classrooms. One can underline that through the gained cost advantages for SME a general strengthening of this kind of enterprises is possible. Thus RELOAD caters the overall long-term strategy of the European Union to foster SME in a sustainable way.

On the technical side the RELOAD platform revealed great flexibility in order to respond to the needs of the learners. The extension of this ability can be seen in the development of a didactical tool box. This would allow different DIY retailers to customise the platform regarding their individual requirements concerning distinct learning approaches (e.g. Blended Learning, e-learning et cetera). Especially the application of the RELOAD platform in a Blended Learning environment would benefit on the implementation of Web 2.0 technologies. Although a feedback function has already been integrated, user generated content would increase the information flow and would be a logical advancement in consideration of the HOT approach.

Through the successful realisation of the RELOAD project the elaboration of new project ideas – which are basing on the key outcomes of RELOAD as well as on further need for research – is impelled by the entire consortium. Thus, e.g. a further need of research can be described with the optimisation of the web interface design for different groups of users and employees. With regard to this, the efforts to continue the work on a sustainable knowledge management and e-learning approach in vocational training will be intensified in future.

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Part III
Cognitive IT-Supported Processes for Heterogeneous and Cooperative Systems

Considering Multi-Evaluation Perspectives in an Agent-Based FMS Scheduling Approach

Ghada Abaza, Iman Badr, Peter Göhner, Sabina Jeschke

Abstract For flexible manufacturing systems (FMS), scheduling approaches have been introduced to achieve optimized schedules while considering multiple optimization objectives. These objectives correspond mainly to the existing evaluation perspectives, namely, the system view and the customer view. The system view corresponds mainly to the maximization of resource utilization. The customer view corresponds to the minimization of jobs-makespans required for customer jobs to finish execution. These correspondent optimization objectives, in practice, are often conflicting and subject to certain constraints. In this paper, an agent-based scheduling approach for FMS is proposed. This approach takes into account both existing evaluation perspectives while generating FMS schedules. It seeks the maximization of the resource utilization and, simultaneously, the minimization of the involved jobs-makespans. Evaluation results recorded near-optimal schedules by the proposed scheduling process.

Key words: Agent-Based Scheduling, Flexible Manufacturing Systems

1 Introduction

Flexible manufacturing systems (FMS) aim at bringing the efficiency of mass production to small-to-medium sized production with high product diversity. They apply flexible resources that enable the production of a wide spectrum of part types

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through computer control, such as computer numerically controlled (CNC) machines. Based on this advanced technology, the same resources can be used to adapt the production to the changing customer needs. Compared to traditional manufacturing systems, the resources of FMS are relatively less in number and are associated with higher investment, which makes the maximization of resource utilization a crucial issue in FMS. The economic viability of FMS is determined by how far they maximize the utilization of the available resources in a way that flexibly adapts the production flow to the changing customer needs. Accordingly, two main views are involved in the assessment of the FMS performance: The system view and the customer view. These two views imply two main objectives, namely the maximization of resource utilization and the minimization of the makespan, or the time required for jobs to finish execution. These objectives are most of the time conflicting [JR98]. Attempting to maximize the resource utilization through the simultaneous processing of more jobs, and consequently through decreasing the idle time would lead to more work-in-progress. This, in turn, costs the jobs being processed longer delay time, waiting on the local queues of the machines. FMS scheduling aims at satisfying these two main objectives through planning the timely allocation of resources to jobs. As a classical optimization problem with conflicting optimization objectives, FMS scheduling is distinguished by its high computational complexity. Traditional scheduling techniques varied from branch-and-bound techniques [DTW99], programming methods [GS05], to the heuristic-based techniques [Che07, AKK03], and recently, the stochastic search techniques such as simulated annealing [LTF07] and genetic algorithms [SPR03, VBE06]. In tackling the scheduling complexity, traditional scheduling approaches have dealt with the problem in isolation from its dynamic environment, which obscured their application in practice [RT90]. In addition, the conventional scheduling approaches deal with the problem in an incomprehensive sense by considering the machines in isolation from other influencing factors, such as the current state of the local buffers which undoubtedly affects the execution of the planned schedule. The agent-based paradigm is strongly advocated for realizing the desired dynamic scheduling for FMS [Lei08]. The goal-orientation and autonomy, associated with agents, aid in tackling the complexity of FMS scheduling. However, this benefit comes at the cost of achieving the required multi-objective optimization due to the myopic view of agents that hinders them from reaching a globally optimized solution. In this paper, a concept for an agent-based multi-objective optimization that accounts for both the customer and the system views is proposed. Based on the presented concept, schedules are generated dynamically and optimized from a global perspective through the negotiations among the involved agents. The rest of the paper is organized as follows. Section 2 discusses the agent-based scheduling for FMS. Section 3 illustrates the details of the proposed scheduling process. Section 4 provides evaluation results. Section 5 concludes with a brief summary and an insight into the future work.

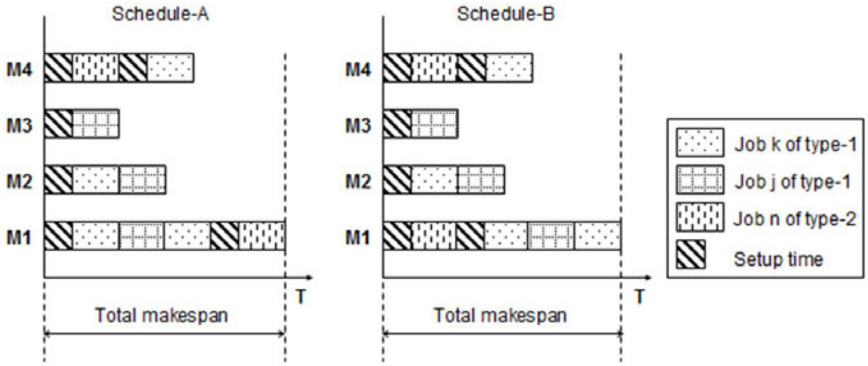

Fig. 1 Sample conflict considering different perspectives

2 Agent-Based Scheduling for FMS

2.1 FMS Scheduling Problem

Manufacturing scheduling is the problem in which a set of jobs have to be arranged in time in order to get processed on one or more finite number of machines [GSST04]. When considering FMS scheduling problem, two main influencing factors have also to be handled. First, the flexibility of machines in performing manufacturing operations gives the possibility of allocating jobs to operations rather than machines. Having multiple machines able to perform some operation, an allocated job to this operation can be executed in parallel. In other words, a job of a certain quantity can be divided into lots that can be executed on the machines in parallel. Additionally, job operations may have a certain order in which they have to be performed. Therefore, allocating the jobs to different operations has also to be verified against the set of precedence constraints between job operations when they apply. The other factor stems from the fact of supporting a wide variety of part types by FMS. Each job is of a certain type. When machines switch from one job to a job of another part type they consume some time, called setup time. Minimizing machine setup times contributes in maximizing the resource utilization.

As previously mentioned, the fully utilization of available resources and the customer satisfaction are significant perspectives for FMS. Mainly, two conflicting objectives correspond to these perspectives. The example depicted in Fig. 1 shows a sample conflict when considering both perspectives.

In Fig. 1, there are three planned jobs: k, j of type 1 and n of type 2. Available machines are: M1, M2, M3 and M4. To maximize the resource utilization, the jobs in schedule A and B, are distributed between available machines providing the ability to execute the requested jobs in parallel. Maximizing the resource utilization by minimizing setup times led to optimized makespans in both schedules. However, in practice, the planned schedule A implies more work-in-progress for job n,

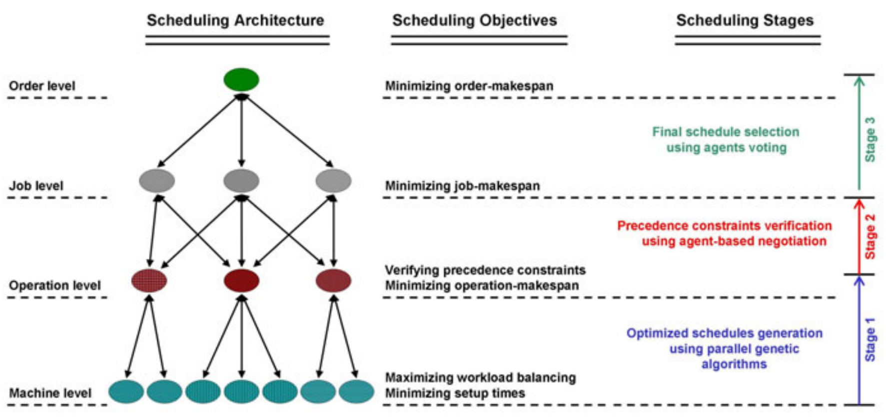

Fig. 2 Objectives and stages of the scheduling process

waiting for job k and job j execution on machine M1. Such a conflict is meant to occur when simultaneously accounting for multiple perspectives by the scheduling process. From the sample above, it can be concluded that:

- Maximizing the resource utilization can be sought by,
  - minimizing machines setup times,
  - maximizing the workload balance between peer machines,
  - and consequently by, minimizing each operation-makespan, i.e., minimizing the elapsed-time required for completing the execution of requested jobs on the associated machines.
- Minimizing the total makespan has also to consider the minimization of each job-makespan, i.e., the minimization of the elapsed-time required to complete the execution of all job operations.

2.2 The Agent-Based Scheduling Architecture

This work extends an agent-based scheduling architecture previously introduced in [Bad08]. The agent-based approach tackles the problem complexity through the goal-oriented decomposition. As shown in Fig. 2, the scheduling architecture is represented by agents at different levels of abstraction. At the lowest abstraction level (the machine level), resources are modeled by agents, in a way that provides a comprehensive coverage to the relevant resources [BG09]. The resource agents providing the same operation are dynamically grouped and managed by operation agents at the next higher abstraction level, namely, the operation level. In addition, jobs are represented as agents (at the job level), to account for the makespan of the individual jobs while optimizing the schedule. Similar to resource agents, job agents are grouped into order agents (at the order level), whose objective is to reach an optimal makespan for the entire job group.

Agents, shown in Fig. 2, have different roles, objectives and functions. Any assigned optimization task to some agent should be compatible with the original objective and function of this agent. Additionally, the aforementioned optimization objectives are shared among the different agents in the architecture. It is not sufficient to let the agents, of different or similar roles, execute their assigned optimization task in isolation. Agents of similar roles have to communicate sharing their knowledge about generated schedules. Agents of different roles have also to communicate the control information between the agents at different levels in the architecture.

3 Agent-Based Scheduling Approach

3.1 Overview on the Scheduling Process

The arrival of a set of jobs that have to be considered when generating the schedule triggers the scheduling process. The set of requested jobs represents an order and corresponds to an order agent. The order agent instantiates associated job agents. Each job agent calls for allocation proposals from the operation agents referring to its work plan. This accords with the agent-based architecture presented in Fig. 2.

The proposed approach distributes first the required optimization objectives between the four levels of the agent-based architecture. This distribution takes into account the different role of the agents at each level. The objectives are to be achieved by the corresponding agents through the three stages of the scheduling process. Figure 2 captures the objectives and the stages of the bottom-up scheduling process.

3.2 Stages of the Scheduling Process

The optimization objectives, with respect to the resource utilization perspective, are assigned to the agents at the machine and operation level. Machine agents cater for minimizing the setup times and maximizing the workload balancing between peer machines. In turn, each operation agent seeks the minimization of its makespan. The optimization objectives, assigned to both operation and machine agents, are pursued by the adopted parallel genetic algorithms (PGA) running at the first stage of the scheduling process [ABGJ10].

Having the optimized schedules generated at the first stage, the scheduling process continues with stage 2 if some precedence constraints apply. At this stage the operation agents verify the generated schedules against the set of precedence constraints. The verified schedules, resulting at the end of stage 2, are forwarded to the third stage of the scheduling process.

At the third stage, each job agent votes on the received schedules with respect to its makespan. The lower the job-makespan implied by a schedule, the higher vote it gets. According to the votes given by the associated job agents, the order agent selects then the final schedule of the lower makespan required for all its requested jobs to be finished, i.e. the order-makespan. Finally, the final schedule is propagated down to all involved agents.

In the following, more details on the tasks achieved by the scheduling process at each stage are given.

3.2.1 Optimized Schedules Generation Using PGA

Genetic algorithms, representing a quick and efficient optimization technique, have been successfully applied for solving FMS scheduling problem [SWH06]. They were chosen, in a previous work, to achieve the assigned optimization objectives at stage 1. The details emphasized here are the ones necessary to complement this work. More details on the adaptation of PGA to the agent-based architecture can be found in [ABGJ10].

Upon collecting the allocation requests from job agents, operation agents initialize the scheduling process at the first stage. They cooperate with the machine agents to generate a set of optimized schedules with respect to the set of assigned scheduling objectives. For this purpose, a PGA is adapted to each operation agent with its associated machine agents. For each operation agent OP_i, there are m available machine agents that correspond to m identical machines performing the same operation. Each machine agent will be responsible for a set of the required jobs to optimize their schedule. Each set assigned to a machine agent is of length l and the jobs assigned to identical machines may overlap.

Operation-level chromosomes are called reference chromosomes (RC). They represent schedules of requested jobs on the associated machines. Each reference chromosome RC_i has the structure: $\mathrm{RC}_i = [C_1, C_2, \ldots, C_m]$ where C_i is the chromosome of the corresponding machine agent M_i. C_i, in turn, has the structure: $C_i = (g_1, g_2, \ldots, g_l)$ where g_i is an identifier of the ith job.

After the termination of the PGA in stage 1, the resulting reference chromosomes will be ready as optimized schedules by which stage 2 continues the scheduling process.

3.2.2 Precedence Constraints Verification Using Agent-Based Negotiation

The operation agents have to examine the resulting schedules from stage 1 with respect to the precedence constraints (PC) on job operations. Schedules that turn to be violating one or more PC will be discarded.

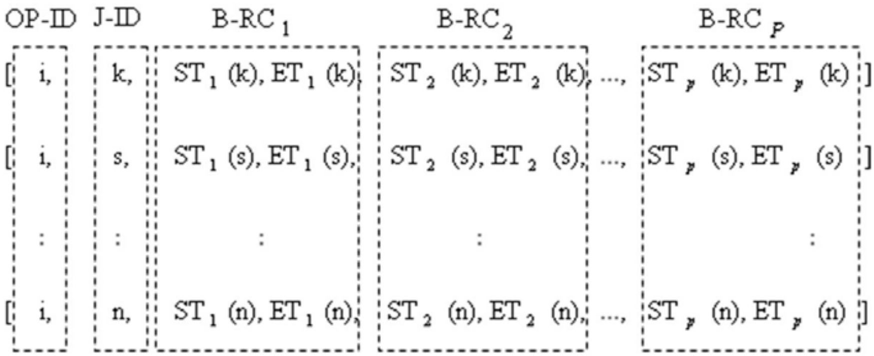

Fig. 3 Sample set of bids vectors

3.2.2.1 Building up the Bids Vectors

The first task at this stage is for each operation agent to reformulate its best RC into a set of bids vectors. For a requested job (J), each RC implies a start time (ST) and an end time (ET) for executing it. The pair (ST, ET) represents a bid for J. The bids vector of J gathers the bids extracted from the RC and mark them by the corresponding operation agent.

- Let $\{J_k, J_s, \ldots, J_n\}$ be the set of requested jobs associated with the operation agent OP_i.
- Let p be the number of generated RC by OP_i.
- Each RC_i imposes a start time $\mathrm{ST}_i(e)$ and an end time $\mathrm{ET}_i(e)$ for each required job J_e.
- Each pair of (ST, ET) represents a bid for the corresponding job.
- The bids of a requested job are formulated into a vector of bids. The vector contains the following information:
  - Operation identifier (OP-ID)
  - Job identifier (J-ID).
  - The bid extracted from $\mathrm{RC}_1(B - \mathrm{RC}_1)$, the bid extracted from $\mathrm{RC}_2(B - \mathrm{RC}_2), \ldots$, the bid extracted from $\mathrm{RC}_p(B - \mathrm{RC}_p)$.
- The bids vectors of OP_i have the structure illustrated in Fig. 3.

3.2.2.2 Building up the Precedence Constraints Graph (PCG)

Verifying the PC between operation agents is guided by a PC graph (PCG). The PCG represents the set of the PC defined on the operations of the requested jobs. It has the following structure:

- PCG vertices represent the requested operations.
- An arc represents a PC associated with a certain job.

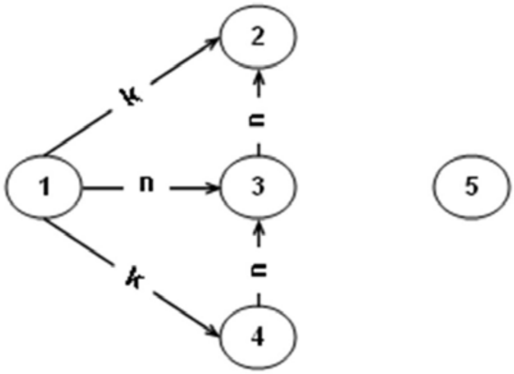

Fig. 4 Sample PCG

- An arc is directed from the preceding operation to the subsequent operation.
- An arc label represents the corresponding job.

Figure 4 shows a sample PCG of 5 operations and 2 jobs.

In this sample:

- $\{J_k, J_n\}$ is the set of requested jobs.
- $\{OP_1, OP_2, OP_4, OP_5\}$ is the set of operations requested by J_k.
- $\{OP_1, OP_2, OP_3, OP_4\}$ is the set of operations requested by J_n.
- $PC_k = \{OP_1 < OP_2, OP_1 < OP_4\}$ is the set of precedence constraints defined on J_k operations (the notation "$OP_1 < OP_2$" in PC_k means that OP_2 cannot start executing a work-piece of J_k before OP_1 finished executing it).
- $PC_n = \{OP_1 < OP_3, OP_3 < OP_2, OP_4 < OP_3\}$ is the set of precedence constraints defined on J_n operations.

3.2.2.3 Negotiating the Bids

Having the bids vectors built, the operation agents that are not involved in any PC can directly deliver their bids vectors to the associated job agents. In Fig. 4, operation agent OP_5 delivers its bids vectors directly to job J_k. On the other hand, the operation agents, involved in one or more precedence constraints, should negotiate the generated bids. Figure 5a depicts the corresponding negotiation between the rest operation agents in Fig. 4, namely, OP_1, OP_2, OP_3, and OP_4. The negotiation conducted between the operation agents is guided by the PCG and achieved by the following procedure.

- Step 1: Exchanging bids vectors. The operation agents, related to each other by one or more PC, exchange their bids vectors. For each assigned job and referring to the corresponding PC, each involved operation agent sends the corresponding bids vector to its consequent operation agents and sets a timer value awaiting

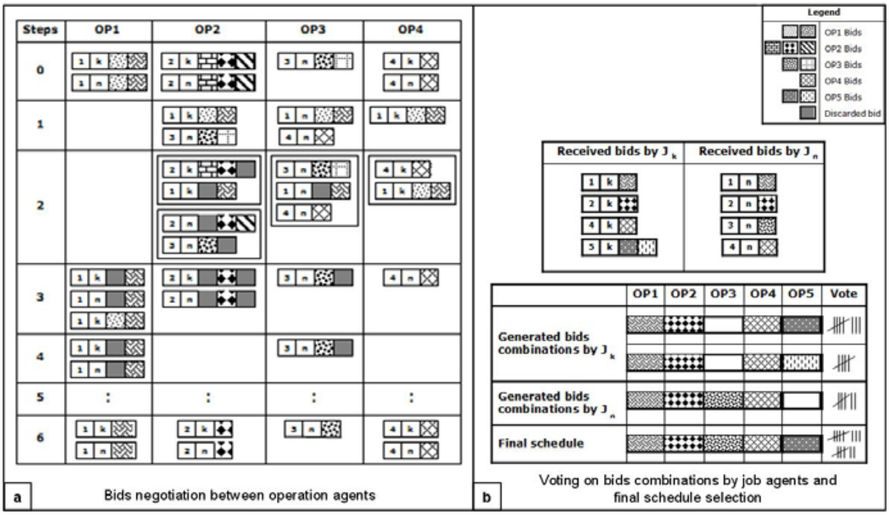

Fig. 5 Sample PC verification and final schedule selection

their feedback. For example, in Fig. 5a, OP_1 sends the bids vector of job J_k to OP_2 and OP_4 while sending the bids vector of job J_n to OP_3.

- Step 2: Evaluating bids vectors. According to the received bids vectors from its preceding operation agents, every involved operation agent evaluates its own bids vectors job-wise. The evaluation discards the own bids conflicting with all received bids and keeps the ones compatible with one or more received bids. This evaluation results in an evaluation vector of the operation agent. Additionally, a vice-versa evaluation is conducted for the received bids vectors. It results in an evaluation vector for each received bids vector. In Fig. 5a, OP_2 evaluates its bids for job J_k with the peers received from OP_1 discarding its third bid and OP_1's first bid. At the same time, it evaluates the bids for job J_n with the peers received from OP_3 discarding its first bid and OP_3's second bid.
- Step 3: Sending back evaluated bids vectors. In this step, the operation agent sends the feedback to the preceding operation agents and updates its own bids vectors. OP_1 in Fig. 5a gets back its evaluated bids from OP_2, OP_3, and OP_4.
- Step 4: Updating bids vectors. Getting the feedback from the subsequent operation agents, the operation agent updates its own evaluation vector discarding or keeping the corresponding bids in its bids vector.
- Step 5: Iterating at step 2. Since the PC contain series of consequent operations, the steps above provide the negotiation between the direct neighboring agents. To insure the propagation of the updated evaluation vectors, the procedure iterates at step 2.
- Step 6: Acquiring final bids vectors. The procedure examines the timer value and terminates if it expired without receiving an updated evaluation vector.

After the termination of the procedure, the involved operation agents end up with the verified bids for each requested job. At this point, each operation agent sends each job agent the corresponding bids vector containing the verified bids. This in turn, triggers the third stage of the scheduling process.

3.2.3 Final Schedule Selection Using Agents Voting

3.2.3.1 Generating and Voting on the Bids Combinations

At this stage, each job agent generates the bids combinations using the received bids from the associated operation agents. Each combination implies a time frame consumed for executing all requested operations by the job agent, i.e. the job-makespan. Depending on this makespan, each combination gets a vote by the job agent. The lower the makespan it implies, the higher vote a combination gets. The job agent sends then a set of its best bids combinations to the associated order agent. Figure 5b shows the resulting bids combinations for job J_k and job J_n according to the sample bids depicted in Fig. 5a.

3.2.3.2 Selecting the Final Schedule

The order agent has the task of selecting the final schedule for the requested jobs. It receives from each job agent a set of bids combinations and their votes. The received bids combinations of one job agent intersect with those of the other job agents sharing one or more requested operations. Therefore, for the job agents, having overlapped bids combinations, it is necessary to unify their selected bid. The order agent intersects the bids combinations of the associated job agents accumulating their given votes as illustrated in Fig. 5b. The best combinations intersection (i.e. the one with the higher vote) is selected as the final schedule. Accordingly, the selected schedule will have the operation bids that show the highest rate of satisfaction to the associated job agents. The selected operation bids are propagated to the corresponding operation agents by the associated job agents. The operation agents, in turn, retrieve the corresponding RC of the received bid and send its constituent chromosomes to the associated machine agents.

4 Application and Evaluation Results

The proposed scheduling process has been tested using the data of an IBM test line described in [Wit90]. It covers a wide range of testers which are classified into tester families. Available part types are grouped into part families. According to the type of the card, a certain set of the tester families are requested. The objective was to reduce the total testing time required for the requested cards, namely the makespan. The makespan is affected by major and minor setup times. Setup times are of more significance in relation to execution time since the latter has a fixed value. The problem is modeled by 31 agents representing the testers. According to the operation they perform, testers are grouped into 4 groups managed by 4 operation agents.

Table 1 Generated makespans considering the resource utilization perspective

Number of jobs	Optimization results Makespan series	Optimality percentage
50	{288, 285, 284, 282, 280, 276, 275, 274, 266, 265, 263}	100 %
70	{471, 460, 412, 392, 386, 383, 374, 360, 352, 351, 350}	75 %
100	{527, 520, 506, 477, 471, 462, 453, 447, 421, 417, 416}	63 %

Table 2 Generated makespans considering the resource utilization and the job-makespan perspective

Number of jobs	Optimization results Makespan series	Optimality percentage
50	{475, 458, 433, 405, 385, 376, 350, 303, 286, 266, 263}	100 %
70	{482, 467, 452, 445, 444, 443, 425, 424, 422, 411, 403}	65 %
100	{556, 544, 522, 473, 445, 444, 441, 439, 435, 434, 430}	61 %

4.1 Resource Utilization Perspective

When considering the resource utilization perspective only, the scheduling process recorded the makespans shown in Table 1. For 50 jobs, the generated schedule converged to the optimal makespan. By increasing the number of considered jobs to 70, and then to 100, a near optimal makespan was reached.

4.2 Job-Makespan Perspective

When additionally considering the job-makespan perspective, the scheduling process recorded the makespans shown in Table 2. For 50 jobs, the final schedule, selected by the scheduling process, met the optimal makespan. For 70 and 100 jobs, the drop in the makespan optimality is relatively small. It is attributed to the added optimization objective, namely the jobs-makespans minimization. The average makespan of each job is minimized by ~60 %.

It can be concluded that the proposed approach achieves a near-optimal makespan when considering both the resource utilization and the job-makespan perspectives. Simultaneously, the involved jobs-makespans are considerably minimized.

5 Conclusions

Manufacturing scheduling considering multi-optimization objectives tends to be a problem of high complexity. It is likely for these objectives to be conflicting, so that they usually get solved with trade-off schedules. In this work, an FMS scheduling approach was introduced. It takes into account two main perspectives, namely, the resource utilization and the job-makespan perspectives. Considering the former while simultaneously accounting for the latter, a near-optimal makespan was reached and the involved jobs-makespans were remarkably minimized.

The proposed approach performs the scheduling process through three stages. The first stage optimizes the generated schedules with respect to the resource utilization perspective. Stage 2 verifies the optimized schedules considering the set of precedence constraints. Stage 3 seeks the minimization of the jobs-makespans and ends up with the final schedule.

It is worthy to mention that the proposed scheduling process may terminate at the end of any stage. It may terminate at the end of stage 1 if no precedence constraints apply and if, for some manufacturing strategy, the jobs-makespans do not need to be considered. The process may also terminate with the verified schedules at the end of stage 2 if some precedence constraints apply and the job-makespan perspective is not considered. Furthermore, stage 2 may be discarded from the scheduling process if no precedence constrains apply and both optimization perspectives are respected. This fact adds more flexibility to FMS scheduling process according to the followed manufacturing strategy and to the applied manufacturing constraints.

Work is ongoing on adapting the proposed scheduling process to environmental dynamics affecting FMS practices. Multiple orders would also be handled in parallel allowing several customer views to apply.

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Extending an Agent-Based FMS Scheduling Approach with Parallel Genetic Algorithms

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Abstract Flexible manufacturing systems (FMS) aim at efficiently reacting to changing market needs to stand the increasing competitiveness. This imposes efficiency and flexibility requirements on FMS scheduling. Manufacturing scheduling is the process of allocating available manufacturing resources to the set of planned jobs over time. It is an optimization process by which limited manufacturing resources are to be allocated to several jobs of different products efficiently. The agent-based scheduling approach has shown the ability to fulfill the flexibility requirement. Although this approach emphasizes flexibility, it lacks the optimization support. In this paper, an agent-based scheduling approach is extended with parallel genetic algorithms (PGA) to provide the required optimization support. Test results have shown a remarkable enhancement to the optimality of the generated schedules with respect to the predefined set of manufacturing objectives. The extended approach fulfils both flexibility and efficiency requirements on manufacturing scheduling.

Key words: Flexible Manufacturing Systems, Parallel Genetic Algorithms, Agent Based Scheduling

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1 Introduction

Since the middle of the 20th century, driven by the need of customers to have products that emphasize their individual personality and by the increasing competition in national and global market, manufacturing systems have been undergoing a revolution. This has led to the development of automated FMS, employing a set of computer-controlled machines. FMS aim at achieving significant improvements in their control functionalities. Out of these functionalities, manufacturing scheduling has been receiving remarkable interest due to its important role in influencing the responsiveness and the efficiency of FMS.

Manufacturing scheduling is concerned with determining the best allocation of the available machines to the planned jobs over time according to a set of predefined objectives and constraints. Seeking optimality of the generated schedule, manufacturing scheduling is regarded as a highly complex optimization problem. In addition, FMS scheduling should exhibit the required responsiveness. In other words, this imposes a challenge of complementing the required flexibility with the required optimization support when solving the scheduling problem.

The agent-based scheduling approach has shown the ability to satisfy the flexibility required for FMS. Nevertheless, this approach lacks the ability to optimize the resulting schedule with respect to the predefined set of manufacturing objectives [Lei08]. The adoption of this approach calls for the integration with an optimization technique. Genetic algorithms (GA), representing a quick and efficient optimization technique, have been successfully applied for solving the manufacturing scheduling problem [SPV02, SPR03, SWH06].

It can be concluded that the combination of the flexibility, attainable by the agent-based approach, and the optimality, pursued by GA, presents a promising enhancement to the performance of manufacturing scheduling systems improving both the efficiency of the generated schedule and the responsiveness of the scheduling process.

This paper addresses the incorporation of PGA into an agent-based scheduling architecture for FMS. This agent-based architecture is introduced previously in [Bad08]. The objective of this work is to bring the flexibility proposed by the agent-based approach together with the optimality introduced by the PGA into FMS scheduling. The rest of the paper is organized as follows. Section 2 discusses the agent-based scheduling for FMS. Section 3 illustrates the details of the proposed scheduling process. Section 4 provides evaluation results. Section 5 concludes with a brief summary and an insight into the future work.

2 Agent-Based Scheduling for FMS

The following subsections highlight the scheduling problem for FMS in general, the agent-based scheduling architecture proposed in [Bad08], and the challenges posed by adopting PGA to this architecture.

2.1 FMS Scheduling Problem

Manufacturing scheduling is the problem in which a set of jobs have to be arranged in order to get processed on one or more finite number of machines [GSST04]. Each job is of a certain part type and a certain quantity to be produced. A job is composed of a set of sub-tasks called operations. The assigned workload to an operation corresponds to the sum of requested jobs' quantities. Due to the flexibility of an FMS, there are alternative machines to execute each operation. Each operation is atomic, i.e. once started it will not be preempted. For the sake of simplifying the situation, each machine can perform only one operation at a time. The machine consumes some time, called setup time, to switch from executing one job to executing a job of another part type.

FMS scheduling can be regarded as a search problem seeking a feasible schedule that satisfies problem constraints. However feasible schedules vary in their quality with respect to a predefined set of manufacturing objectives. Consequently, FMS scheduling, when searching for the best schedule among feasible schedules, turns into an optimization problem with some objective function(s) to optimize. To solve this problem, the scheduling process should gurantee the flexibility of the FMS and the optimality of the generated schedules.

2.2 The Agent-Based Scheduling Architecture

This work extends an agent-based scheduling architecture previously introduced in [Bad08]. The proposed architecture consists of four levels of abstraction modelling physical and logical entities involved in the scheduling problem as agents. These levels correspond to machines, operations provided by these machines, jobs, and orders of jobs with common constraints. Figure 1 captures the agent-based architecture. For a more detailed discussion of the agent-based modelling and its gained advantages, the interested reader is referred to [Bad08], [BG09a] and [BG09b].

2.3 Challenges of PGA Adoption

Although GA have the ability to find good solutions, the time required for the search to converge exceeds as the problem size gets bigger, demanding higher computational resources [Can98]. This resulted in the need for parallel implementations of GA to speed up the GA performance [Can99]. Parallel implementations of GA distribute the computational load among several resources introducing the PGA. In a PGA, several communicating nodal GA called "demes" evolve simultaneously to solve the same problem [Can99].

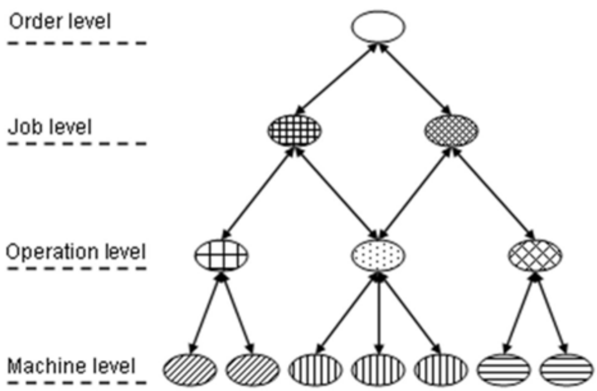

Fig. 1 Agent-based scheduling architecture for FMS

Concerning the FMS scheduling problem, the adoption of PGA to the agent-based architecture, depicted in Fig. 1, is not a straightforward process. Agents with different roles cannot be considered as equivalent resources to execute a PGA. Any assigned evolution task (a deme) to some agent, by the PGA, should be compatible with the original objective and function of this agent.

Additionally, the predefined manufacturing objectives that should be optimized are shared among the different agents in the architecture. It is not sufficient to let the demes, executed by agents of different or similar roles, to evolve in isolation by each agent. Agents of similar roles have to communicate sharing their knowledge about generated schedules. Agents of different roles have also to communicate the control information between the agents at different levels in the architecture.

Moreover, the adopted PGA has to maintain the flexibility of the agent-based architecture. Allowing the demes to evolve over generations without convergence control and to communicate according to a fixed topology would reduce the responsiveness of the involved agents. Providing required measures on the evolution process of each deme and introducing suitable tunings to their performance, could lead to better schedules and faster convergences.

The proposed approach introduces a scheduling process that adapts PGA to the agent-based architecture maintaining the flexibility and optimality requirements.

3 Agent-Based Scheduling Using PGA

3.1 Overview on the Scheduling Process

The arrival of a set of jobs that have to be considered when generating the schedule triggers the scheduling process. Within this work, the set of simultaneously re-

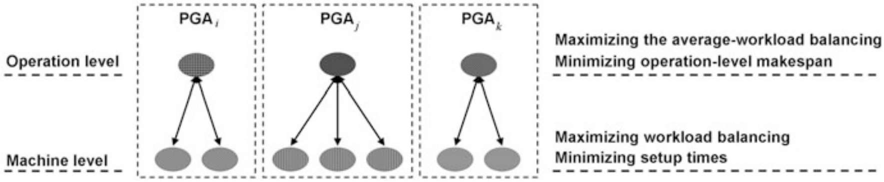

Fig. 2 Optimization objectives of the scheduling process

quested jobs represents an order of a certain customer and corresponds to an order agent in the architecture. The order agent instantiates associated job agents. Each job agent calls for allocation proposals from the operation agents referring to its work plan. This accords with the agent-based architecture presented in Fig. 1.

The optimization objectives are distributed between the agents at the machine and operation levels of the agent-based architecture. This distribution takes into account the different roles of the agents at each level. Figure 2 captures the scheduling objectives assigned to the agents at each level.

To achieve the assigned scheduling objectives, a PGA will be adapted to each operation agent with its associated machine agents. On one hand, the adaptation of the PGA at the operation level seeks the minimization of the makespan required for performing the requested jobs on the associated machines, i.e. the operation-level makespan. Simultaneously, it aims at keeping the average workload of the associated machine agents balanced. On the other hand, the adaptation of the PGA at the machine level caters for minimizing the setup times and maximizing the workload balancing between peer machines. It is worth mentioning that while minimizing the operation-level makespan by each operation agent, the total makespan consumed for executing the whole set of requested jobs is also minimized.

Figure 3 shows an illustration of the proposed scheduling process considering one operation agent and three associated machine agents. Details on the process initialization and the PGA adaptation are given in the following subsections.

3.2 Scheduling Process Initialization

Upon collecting the allocation requests from job agents, operation agents initialize the scheduling process. Since each operation agent has a set of machines performing the same operation, the requested jobs are distributed between the machines which, in turn, perform the assigned jobs in parallel. Maintaining an even distribution of the jobs between the available machines implies better machine utilization and consequently lower makespans. Therefore, each operation agent has to consider the corresponding job quantities when distributing the jobs between the associated machine agents. The higher the quantity of a certain job, the more machines are allocated to perform it. This initial distribution forms a reference schedule, allocating the requested jobs on the associated machines.

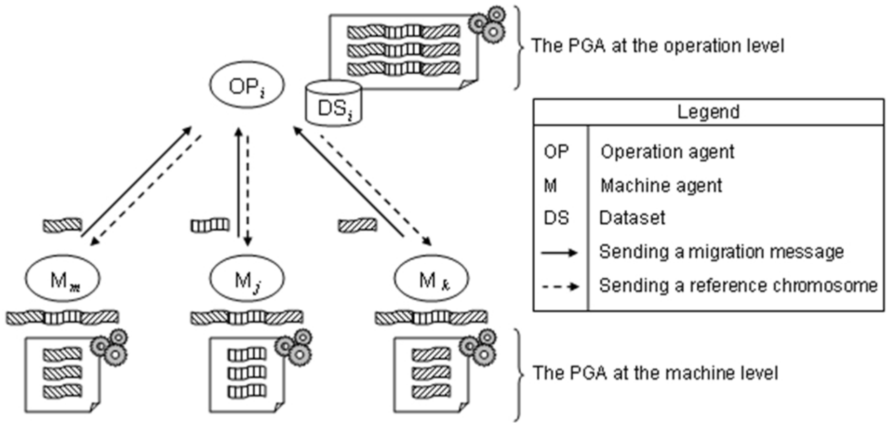

Fig. 3 Illustration of the proposed scheduling process

The reference schedule will be represented as a reference chromosome (RC) and will be sent to each associated machine agent. The PGA executed by the associated machine agents will use the received RC while generating optimized schedules. The newly generated schedules at the machine level will depend on the corresponding RC to keep their workload balanced.

Assuming:

- For each operation agent OP_i, there are m available machine agents that correspond to m identical machines performing the same operation.
- Each machine agent will be responsible for a set of the required jobs to optimize their schedule. Each set assigned to a machine agent is of length l and the jobs assigned to identical machines may overlap.
- RC_i has the structure: $\text{RC}_i = [C_1, C_2, \ldots, C_m]$ where C_i is the chromosome of the corresponding machine agent M_i.
- C_i has the structure: $C_i = (g_1, g_2, \ldots, g_l)$ where g_i is an identifier of the ith job.
- Each job j_i has a certain quantity q_i and a number of occurrences o_i in RC_i. The higher the quantity of a job is, the more lots it gets on the available machines. Given j_i, j_k and the corresponding q_i, q_k, if $q_i < q_k$ then $o_i < o_k$.

The length of a machine chromosome is calculated as follows:

- $l = \text{ceil}(O/m)$, where:
- $O = \sum_i O_i$ is the total number of job occurrences in RC_i.
- For each job j_i, $o_i = m^*(c_i/100)$.
- For each job j_i, $c_i = 100^*(l_i/\text{MAXL})$ is the percentage value of the number of the machines allocated for j_i.
- $\text{MAXL} = \max_i(l_i)$ is the maximum number of lots given to a job.
- For each job j_i, $l_i = (q_i/EW)$ is the total number of its lots on the associated machines.

- $\mathrm{EW} = \mathrm{ceil}(W/m)$ is the even workload of one machine associated with OP_i.
- $W = \sum_i q_i$ is the total workload of the jobs requesting OP_i.

OP_i determines also the ideal workload IW_i of one associated machine and the range R_i of workload amounts that will be considered as balanced for one associated machine. R_i and IW_i are calculated as follows:

- For a given threshold ξ_i, R_i amounts to $\mathrm{IW}_i \pm \xi_i$.
- $\mathrm{IW}_i = \mathrm{ceil}(1/m^* \sum_{k=1}^{m} \lambda_k)$, where:
- $\lambda_k = \sum_{i=1}^{l} p_i$ is the number of assigned job work-pieces to each machine agent.
- $p_i = \mathrm{ceil}(q_i/o_i)$ is the resulting allocated quantity p_i of each job j_i assigned to a machine agent.

3.3 Adaptation of the PGA at the Machine Level

After receiving the RC from the corresponding operation agent, associated machine agents start up a PGA. Each machine agent gets one deme to execute. The objective of each machine agent is to optimize the generated sub-schedules of the associated machine by reducing the setup times and by increasing the workload balancing. Machine agents, while executing the assigned demes, share their knowledge through the migration operator and they are controlled by the associated operation agent; see Fig. 3.

In what follows, the adaptation details concerning the initialization, the fitness function, the reproduction and the migration operator are discussed.

3.3.1 Initialization

Each machine agent M_i uses the received RC to generate the initial population of the corresponding deme. For this purpose, M_i generates a set of permutations of the genes of its chromosome C_i in the RC. The resulting chromosomes are considered as the initial population of M_i.

3.3.2 Fitness Function

The PGA at the machine level has a multi-objective evaluation function. The fitness function f is a combination of two evaluation functions. One evaluation function f_t corresponds to the objective of reducing the setup times. While pursuing this objective, the PGA has to keep the workload of each machine from drifting far from the ideal workload IW (previously assigned by the operation agent). Therefore, the other evaluation function f_w corresponds to the objective of increasing the workload balancing. Each evaluation function has a certain weight relative to the other evaluation function. Weight values w_t and w_w are configured by the user.

- $f_t(C)$ is the sum of the setup times imposed by a chromosome C.
- $f_w(C) = |\mathrm{IW} - \lambda|$ is the difference between the ideal number of job work-pieces assigned to one machine agent (IW) and the number of assigned job work-pieces (λ) implied by C.
- $f(C) = w_t^* f_t(C) + w_w^* f_w(C)$ is the fitness function whose value is to be minimized by the PGA at the machine level.

3.3.3 Reproduction

At each machine agent M_i, parent chromosomes are to be selected to produce new offspring. The parent chromosomes are selected either from the current population at M_i or from the neighboring chromosomes in the RC. For this purpose, a random number $r \in [1 \ldots m]$ is generated. If ($r = i$), parent chromosomes are selected from the best chromosomes in M_i current population. Otherwise, one parent chromosome is selected from the best chromosomes in M while the other parent chromosome C_r is selected from the RC.

Having selected the parent chromosomes P_1 and P_2, multi-point crossover operator is used to generate the new offspring. In case of generating duplicate offspring, the diversity of the generated offspring is emphasized by M_i. First, new combinations of the genes of the parent chromosomes are generated. Then, a set of permutations on the resulting combinations are performed. The next example illustrates these operations.

- Let $P_1 = (5,4,2)$, $P_2 = (5,4,3)$.
- Regardless of their sequence in parent chromosomes, the parent-genes are used to generate possible new offspring, such as: (5, 3, 2), (4, 3, 2).
- Possible permutations on the generated offspring are applied, such as: (5, 2, 3), (4, 2, 3), etc.

Among the offspring generated for each set of parents, only balanced new chromosomes are selected for applying the possible permutations while the others are discarded. A chromosome C is considered as balanced if $f_w(C) \leq \xi$.

Newly generated chromosomes will replace the worst chromosomes in the next generation.

3.3.4 Migration Operator

The migration operator of the PGA is designed so that it will not initiate needless communication. The migration of chromosomes between the evolving demes is decided dynamically depending on the progress of their evolution process yielding guided migration rate and interval. Determining the recipient deme during the execution implies a dynamically defined migration topology. Agents at both the machine and the operation level are involved in realizing the migration operator.

Each operation agent OP works as a mediator for controlling the evolution status and the migration operations of the demes evolving on the associated machine agents; see Fig. 3. For this purpose, each operation agent manipulates a local dataset DS which has the following content.

- The mean fitness reached by each deme.
- A set of the best chromosomes generated and sent by each deme and their corresponding fitness values.

After a certain number of generations, configured by the user, each M sends a message M to the associated operation agent. M $= (i, SC_i, sf_i, mf_i)$ where,

- i: The machine agent identifier.
- SC_i: A set of the best chromosomes in the current population of M_i.
- sf_i: The corresponding set of fitness values of SC_i chromosomes.
- mf_i: The mean fitness of the current population of M_i.

Upon receiving a message from M_i, the corresponding operation agent determines the status of the evolution process at M_i by comparing the mean fitness of M_i received in the message M with the peer value stored in its dataset. If both values turned to be similar, it indicates that the deme at M_i is approaching its convergence. Therefore, the operation agent decides on sending a new RC (generated at the operation level as it is described in the following subsection) to M_i. Then, the operation agent updates its dataset according to the received message information.

Upon receiving a new RC from the associated operation agent, the machine agent M_i replaces its current RC with the received RC and considers the latter starting the next generation.

The termination of the PGA at the machine level is determined by the corresponding operation agent as mentioned below.

3.4 Adaptation of the PGA at the Operation Level

The PGA at the operation level combines the generated chromosomes by the associated machine agents into reference chromosomes. The PGA at the operation level has two objectives: one objective is to maximize the average-workload balancing of the constituent chromosomes while the other objective is to minimize the operation-level makespan. Whenever a new RC is generated, it is subjected to a feasibility test that insures the existence of all requested jobs in it. Infeasible reference chromosomes are discarded. The generated reference chromosomes form a set of complete schedules that will compete for being selected as the final schedule for the requested jobs of the operation agent.

In what follows, the adaptation details concerning the initialization, the fitness function, the reproduction and the termination condition are discussed.

3.4.1 Initialization

Referring to its stored dataset, each operation agent creates its initial population of RC by generating different combinations of the chromosomes sent by the associated machine agents.

3.4.2 Fitness Function

The PGA at the operation level has a multi-objective evaluation function. The fitness function op_f is a combination of two evaluation functions. The first evaluation function op_f_w corresponds to maximizing the average-workload balancing of the RC which depends on the workload implied by its constituent chromosomes. The other evaluation function op_f_t corresponds to minimizing the operation-level makespan (the time frame required for the operation to finish the processing of all assigned jobs). Each evaluation function has also a certain weight configured by the user. Weight values are op_w_w, op_w_t.

Given:

- An RC $= [C_1, C_2, \ldots, C_m]$.
- Workload values of the constituent chromosomes $[\lambda_1, \lambda_2, \ldots, \lambda_m]$.

Then,

- op_$f_w(\text{RC}) = |\text{IW}_i - (1/m * \sum_{k=1}^{m} \lambda_k)|$.
- op_$f_t(\text{RC})$ is the sum of the setup times and processing times consumed for performing the requested jobs according to their sequence in RC.
- op_$f(\text{RC}) = w_w *$ op_$f_w(\text{RC}) + w_t *$ op_$f_t(\text{RC})$ is the fitness function whose value is to be minimized by the PGA at the operation level.

3.4.3 Reproduction

Each operation agent refers to its dataset to generate the new RC of the next generation by generating possible combinations of the stored chromosomes. The stored chromosomes in the dataset are frequently updated by the received migration messages from the associated machine agents. As mentioned before, only feasible RC will be considered for the population in the next generation.

3.4.4 Termination

The PGA at the machine level terminates when receiving a termination message from the associated operation agent. The operation agent, in turn, terminates the PGA at the machine and operation levels when one or more of the following termination criteria are satisfied.

- A predefined fitness value was reached.
- The number of generations exceeds a predefined limit.
- The evolution time exceeds a predefined limit.
- No improvements have been recorded on the fitness values over the past G generations, where G is configured by the user.

After the termination of the PGA, the best reference chromosome will be selected as the final schedule. The operation agent will send each constituent chromosome of the final schedule to the corresponding machine agent.

4 Application and Evaluation Results

The proposed process has been tested using the data of an IBM test line described in [Wit90]. It covers a wide range of testers which are classified into tester families. Available part types are grouped into part families. According to the type of the card, a certain set of the tester families are requested. The objective was to reduce the total testing time required for the requested cards, namely the makespan. The makespan is affected by major and minor setup times. Setup times are of more significance in relation to execution time since the latter has a fixed value. The problem is modeled by 31 agents representing the testers. According to the operation they perform, testers are grouped into 4 groups managed by 4 operation agents.

4.1 Influence of Varying the Number of Requested Jobs

The number of jobs, simultaneously requested by an order agent, affects the quality of the makespan reached by the scheduling process. Figure 4 depicts the makespan recorded over 30 generations considering a group of 50, 70, and 100 jobs. Increasing the number of the simultaneously requested jobs delays the convergence to a near-optimal solution. For 50 jobs, the optimal makespan was reached by the 23rd generation. The convergence to the optimal makespan is delayed in case of the 70 and 100 jobs. Increasing the number of generations, as the figure shows, increases the probability of approaching the optimal makespan. This is attributed to the fact that the makespans, reached by the PGA, do not deteriorate over generations. As a measure of responsiveness, the computational time of every generation was found to be 0.6 seconds at a 1.73 GHz processor.

In other words, the achieved enhancement to the optimality of the generated schedules is combined with maintaining the flexibility and responsiveness of the agents.

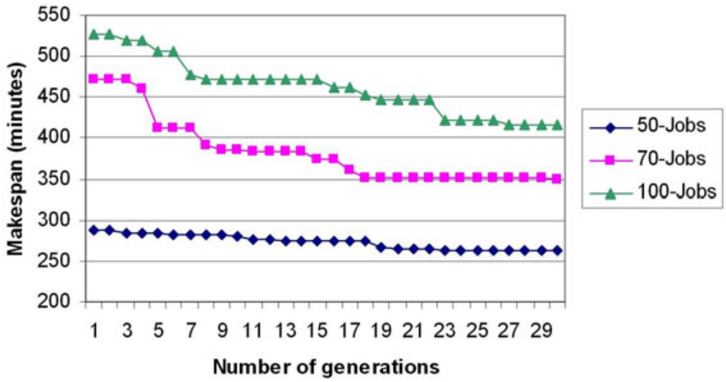

Fig. 4 The effect of varying the number of jobs on the resulting makespan

4.2 Influence of the Multi-Objective Optimization

The purpose of this experiment is to measure the effect of the multi-objective optimization on each constituent objective.

Figure 5 illustrates two test scenarios. In the first scenario, only the makespan optimization was considered. In the second scenario, the optimization of both the makespan and workload balance was considered. While the makespan in the first curve features a continuous enhancement, the other curve shows variations in the makespan. The decrease in the makespan over generations is compensated by an enhancement with respect to the other optimization objective, namely, optimizing the workload balance.

Figure 6 depicts the influence of considering the makespan optimization on the resulting workload balance. Since the initial RC, built by each operation agent, has

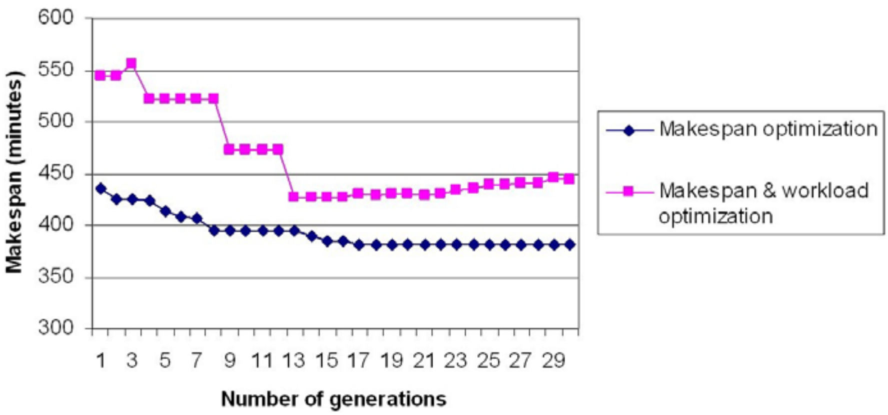

Fig. 5 The effect of optimizing the workload balance on the resulting makespan

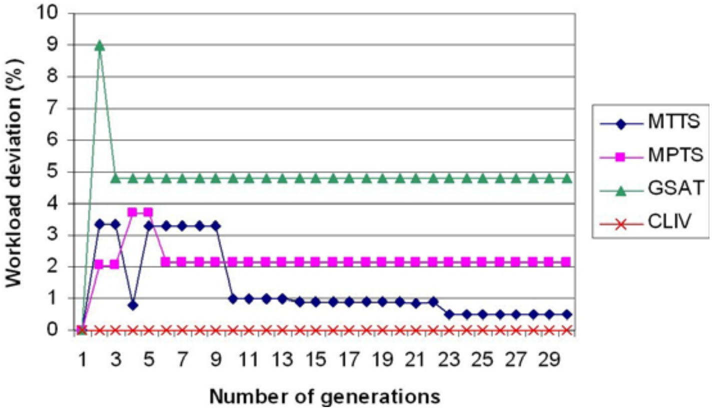

Fig. 6 The effect of optimizing the makespan on the resulting workload

the workload of the requested jobs evenly distributed between machine agents, the PGA starts with the optimal workload. The algorithm tries then not to drift far from the optimal workload over generations while optimizing the makespan. The figure shows the percentage value of the deviation of the resulting workload from the optimal workload, over generations for each operation agent: MTTS, MPTS, GSAT, and CLIV. Drifting from the optimal workload at the early generations, each PGA keeps trying to reduce the difference between the resulting workloads and the optimal workload. The late generations of each PGA, as depicted in Fig. 6, show closer workloads to the optimal workload.

It can be concluded that the optimality of the generated makespan is affected when the PGA considers alongside the workload balancing and vise versa.

5 Conclusions

Scheduling for FMS has been associated with the challenge of combining efficiency with flexibility. Its high potential in reacting to the complexity and dynamics of the problem brought the agent-based paradigm to the forefront of the proposed scheduling approaches. Nevertheless, adopting this paradigm is hindered by its lack of optimization support to the resulting schedules. The decentralization of the agent-based paradigm calls for an optimization technique that takes the different roles of the agents into consideration. This work contributes in incorporating parallel genetic algorithms into an agent-based architecture, which has been proposed in a previous work.

The optimization objectives of the scheduling process were distributed among the agents with respect to their assigned roles. The attainable optimality of the generated schedules was reached in small computational times ensuring the desired responsiveness.

Work is ongoing on taking more evaluation perspectives for the generated schedules into consideration. A concept for a more sophisticated scheduling process that combines the production and the customer evaluation perspectives is under investigation. The concept will handle multiple orders at a time and benefit from the optimality of the generated schedules at the machine and operation levels to build up further optimizations at the job and order levels.

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A MDV-Based Approach for Appearance Enhancement of Historical Images

Mohammad Alfraheed, Ahmed Alamouri, Sabina Jeschke

Abstract The approach based on the Mahalanobis Distance Value (MDV) is introduced for appearance enhancement of objects included in images; and especially for study cases dealing with historical images. In those cases, this approach allows an automatically reducing of the noise pixels and distortion parameters associated with an image. First of all, an image is divided into Seed Regions (SRs) based on watershed transformation. Each SR created is divided into non-overlapping subregions based on the Intensity Values (IVs) associated with (MDV). Subregions which have the same MDV and different intensity values have to be separated. Therefore, the subregion with the minimum MDV is considered as Reference Partition (RP) used for the separation process. IVs of a final generated subregion are replaced by the IV which has the largest frequency associated with. As a result, each subregion takes a new color which is relatively close to its original color but more clear and low gradient. The performance of the MDV-based approach is expressed through a comparison to other approaches used for appearance enhancement of images (like: Gaussian filter).

Key words: Historical Images, Image Distortion, Appearance Enhancement, Edge Detection

1 Introduction

The resolution of an image plays an important role in automated object recognition. Usually, a high image resolution improves this process. Unfortunately, a high image resolution is not always available (e.g. historical images). In this context, most of

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historical images are of analogue types and have to be scanned in order to obtain digital data. These new digital data often include different distortion parameters (e.g. radial parameters). This leads to new challenges for image understanding. In this article, an effective approach for the appearance enhancement of objects (e.g. buildings, parts of buildings) included in historical images will be investigated. Hereby, noise pixels and distortion parameters will be automatically reduced.

The principle of our contribution, which is called MDV-based approach, depends on processing small object partitions of the historical image instead of the whole object. Therefore, the MDV-based approach enhances the small parts of the image's objects. In this approach, the term "Seed Region (SR)" is here defined for representing the semi-similar intensity values through a closed region. In SRs the scattered intensity values (which form the subregion) prevent the MDV-based approach to estimate the representative color of the subregion. The MDV-based approach adopts these scattered intensity values through redistributing them into subregion using MDV which is a multivariate measure of the separation of the data set in space [GEW04]. The subregions which represent the levels of the MDV (except the first level) still prevent the MDV-approach to estimate the representative intensity values. Therefore, the MDV-based approach considers the first level of the MDV as a reference subregion used for the separation process.

As a result, each partition will take a new color which is relatively close to its original color but more clear and low gradient. The suggested approach has several advantages over previously used methods (e.g. Gaussian Filter) which have been introduced by Gonzalez et al. [GEW04] for enhancing the appearance of the gray level images. The drawback of their developments is that these methods convergent the IVs based on static parameters instead of enhancement of the whole image. Furthermore, the approach enables more accurate object detection because the object's edges, which are generated from enhanced images, are clearer than those edges generated from un-enhanced images.

The investigations and implementations of the experiments achieved in this approach are based on the data acquired from the historical aerial images of Baalbek in Lebanon. These photos were taken in the year 1937 through the French mandate and located in the institute of ***Francais du Proche Orient*** (IFPO) in Damascus as celluloid photographic film. They were performed on glass sheets with the size of 18×13 cm with four fiducial points. These images were scanned and sent to University of Technology Cottbus in Germany. Unfortunately the resolution of the scanner used is unknown, but by using image processing softwares (e.g. Adobe Photoshop CS2) it can be found that the photo's resolution is 96 dpi (dots per inch), i.e. the size of a pixel is $\sim 0.25 \times 0.25$ mm.

In Sect. 3, the principle of the MDV-based approach and its four phases are expressed. Furthermore, we present the experimental results of the approach in Sect. 4. Finally, we denote our conclusions and pose some ideas for future work.

2 Related Work

Image appearance has a direct impact on image understanding; especially for historical images which are in most cases available only in analogue form. The scan-process of analogue images requests a superior performance in order to collect the data set without any type of distortion. In the context of the superior performance, the ability of UltraScan500 (a modern photogrammetric scanner manufactured by Vexcel Imaging Austria) to transform analogue images into digital format was discussed by Gruber & Leberl [GL01]. In addition, they introduced an approach for color enhancement within the scanning process in which images are scanned in parts. This leads to distortion factors (either photogrammetric or color factors). These factors are still available in the appearance of the historical aerial images. Therefore, Yuzhong & Jakkula [SJ07] have been developed two algorithms for removing the effects of the scattering and absorptions which represent the atmosphere effects. In the study case of Baalbek's historical images, both algorithms are not applicable for processing the distortions presented here because they require that the distortions affect on the whole image evenly. In our case, the distortion type of historical images of Baalbek affects unevenly on parts of the image.

In several image processing applications, the main purpose of the image enhancement is to detect the objects edges. Starting with this principle, Mansoor and et al. [BMKK08] suggested an approach which detects the edges of the various objects in aerial images. Based upon fuzzy morphology, these edges are undergone to enhancement process as required. The result of this process enables to detect and enhance the required objects whose edges are approximately clear, whereas unclear objects will be eliminated. This conflicts with the objective of this work which deals with all objects in the image. Therefore, fuzzy morphology based approach cannot be applied for our purpose.

Different methods of the spatial and frequency domain had been proposed for enhancement of historical images (Shi et al. [SSG05, SSG10, SG04], Agam et al. [ABFF07], Wang et al. [WXLT03], Yahya et al. [YAO$^+$09]). These approaches depend on an estimation of the background color for separating the background and objects of historical images from each other. In this context, it is difficult to apply these methods to Baalbek's images because the historical aerial images are composed of objects contiguous with each other. Therefore, there are no visible features describing the images' background.

According to Gonzalez & Woods [GW02], the canny detector – which is an important filter used for edge detection – enhances the image at the initial step. The enhancement process depends on the usage of Gaussian filter which groups the semi-similar intensity values together based on the value of Standard Deviation SD. Performance of the Gaussian filter had been proved in several types of digital images. In the filter, the value SD should be already given as appropriate value. As a result, the intensity values of the whole region of the object in historical aerial image are replaced by a certain intensity value, whereas the whole region consists of different subregions. Starting from this challenge, another criterion will be investigated. It depends on grouping the semi-similar regions and redistributing the whole region of the object in historical aerial image based on MDV.

3 MDV-Based Approach

The main core of the MDV-based approach depends on processing the seed regions generated by grouping the semi-similar regions together. These semi-similar regions will be redistributed based on MDV. This process aims to increase the opportunity for extracting the noise intensity values. In addition, the new subregions of the image's objects on the historical images are determined. Consequently, the appearance of the objects on the historical images is improved as a result of the noise reduction. Furthermore, objects of the historical images are identified for analysis process. The principle of MDV-based approach consists of four stages which are shown in Fig. 1.

3.1 Creation of the Seed Regions

A seed region is an extension of the seed point which has been introduced in region growing algorithm [GW02], for initializing the segmentation operations. In this work, the seed region is an initial closed region of the intensity values. It refers to groups of semi-similar intensity values instead of using an intensity value for initializing the enhancement process. This enables to deal with object partitions of the historical aerial images instead of a whole object. The approach enables therefore to enhance small parts of objects. In addition, the noise intensity values will be limited just in those small parts.

A basic method used for creation of a seed region is the manual selection of the required regions. This has an impact on reducing the efficiency of the MDV-approach; therefore this method is not desirable to be applied here. In several cases, the morphological operations [GW02] are used to generate the required seed region automatically. In the case of historical aerial images, the object edges generated by morphological operations are not connected together. In addition, to link these edges, several morphological operations should be repeated many times on the historical aerial images. That leads to hide many parts of objects in edges. Therefore, the challenge related to the non-closed edges prevents the seed regions to be generated by morphological operations. This challenge has been solved by the watershed transformation Gonzalez & Woods [GW02, GEW04]. Generally, the watershed transformation is a powerful tool for image segmentation. By viewing an image as a geological landscape, this transformation considers any image as a topographic surface flooded by water from its minima. Watershed lines determine the boundaries that separate image regions. The watershed transform is applied to gray scale images to resolve a variety of intensity values and to segment the closed region in the image. The segmentation process of the watershed transform depends on extract-

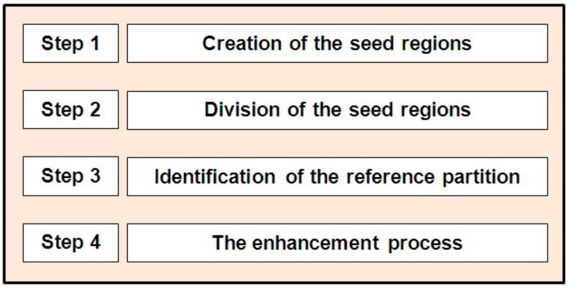


Fig. 1 Main steps of the MDV-based approach

ing the watershed boundaries which divide the regional minima (M) in each other. The height of the regional minima is proportional to gray scale values (intensity values) in the historical aerial image. In addition, the transformation requires that each regional minima has a catchment basin $C(M)$ associated with regional minima. $C(M)$ denotes a set of coordinates of points in a catchment basin. In practice, the transformation operation is performed to express the following values:

$$T(n) = \{(s,t)\,|\,g(s,t) < n\}, \tag{1}$$

$$C_n(M_i) = C(M_i) \cap T(n), \tag{2}$$

where:
g: input image, s, t: the index of the width and the height respectively, n: an increment value representing the height of the regional minima.

The heights of the regional minima are arranged from $(\min + 1)$ to $(\max + 1)$, so that the min and max are the minimum and maximum intensity values of the image, respectively. The result of (1) represents the coordinates set of the points in image (g) lying below the plane (n), whereas the $C_n(M_i)$ represents the coordinates of the points belonging to a set of catchment basin as well as they satisfy the $T(n)$ conditions. In order to construct the watershed boundaries (object edges), both $C_n(M_i)$ and $C_n(M_{i+1})$ are compared together based on intersection operation $\cap$. If there is an overlapping between both sets, the border is determined between $C_{n-1}(M_i)$ and $C_{n-1}(M_{i+1})$. Otherwise, both (M_i) and (M_{i+1}) are grown. The result of the watershed transformation applied is shown in Fig. 2.

3.2 Division of Seed Region

Based on the watershed transformation an image's objects could be extracted based on the background. Figure 2b shows the results yielded by applying the watershed transformation to the historical image. These results reveal that the detected edges do not determine exactly the required object because the intensity values of that ob-

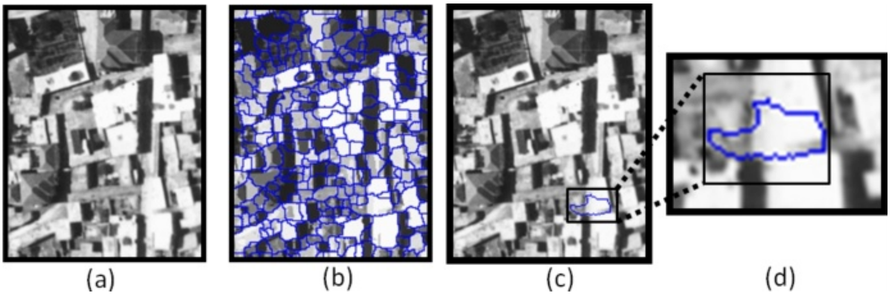


Fig. 2 The results of the watershed transformation; **a** original image, **b** image based on watershed transformation, **c** a sample of a seed region created and **d** a close view (zoom in) of the seed region created

ject do not vary smoothly. Despite the watershed transformation did not extract the required objects exactly but it created the seed regions successfully. However, the seed regions compose of scattered values which form different subregions. Therefore, the estimation of a certain intensity value will be invalid to represent the seed region. To overcome this challenge, the seed regions should be divided into subregions. That enables the MDV-based approach to enhance subregions which are smaller than seed regions. In addition, the intensity value estimated in the next phase will be more exclusively.

In practice, one of the suggested solutions for redistributing the intensity values of the seed region is to generate an optimal threshold value. Unfortunately, the histogram process of these values – which is a tool for generating the threshold value – is not able to adopt these scattered values because these values need more than a threshold value. In addition, the result of the redistributions will not be accurate. The basic method to find the threshold value is not applicable here.

The solution presented here adopts these scattered values depending on MDV in redistributing the intensity values. The MDV has been introduced in linear discriminant analysis of the statistic [Geo92]. In this article, the MDV has been used to measure the distance between each intensity value of the seed region and the same set of the intensity values. MDV is calculated as following:

$$D_m X = \sqrt{(x-\mu)^T S^{-1}(X-\mu)}, \tag{3}$$

where:
X: intensity value, μ: the mean of intensity values associated with a seed region, S: covariance matrix, $D_m(X)$: MDV of the value X.

Intensity values of the seed region have been distributed based on MDV (cf. Fig. 3a). In addition, the subregions are not overlapping. In Fig. 3b, the yielded subregions have been colored to illustrate the results in the historical aerial image.

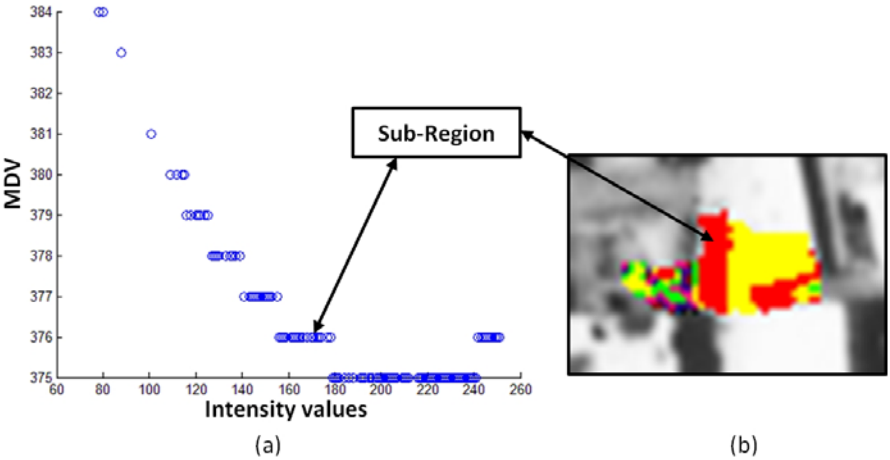


Fig. 3 Results of the division process of seed regions; **a** the histogram of a partition based on intensity values and MDV, **b** illustration of the divided seed region

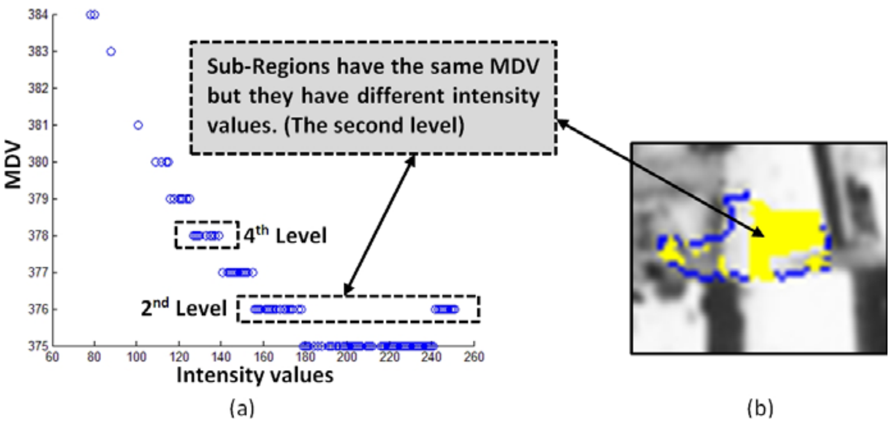


Fig. 4 The estimation of a certain intensity value for each subregion. In this context, **a** shows the histogram of subregions based on intensity values and MDV, **b** a view of subregion with the same MDV and different intensity values

3.3 Identification of the Reference Subregion

The benefit achieved from division of seed regions is to facilitate the estimation task which aims to find a certain intensity value for each subregion. Due to that there are two subregions with the same MDV and different intensity values, a new problem is arisen which prevents the estimation task to be applied. To illustrate this problem clearly, Fig. 4 shows that the second level of the MDV equals 376 and the same level has two ranges of intensity values. Therefore, it is difficult to represent these ranges by a certain intensity value.

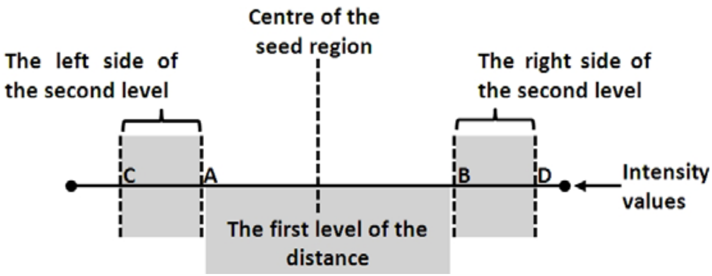


Fig. 5 An Illustration of ranges of the MDV levels

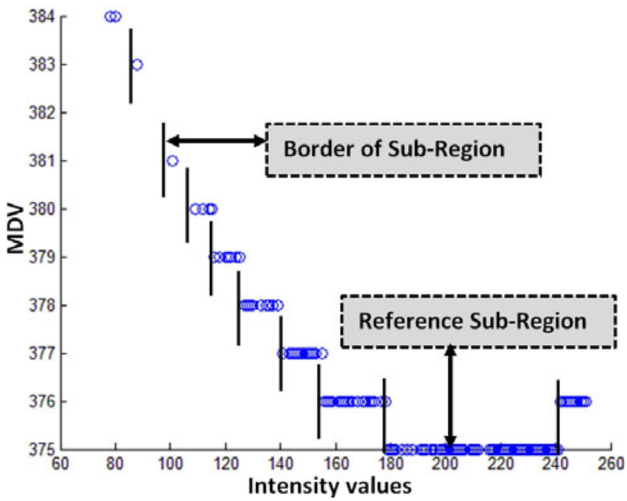


Fig. 6 The histogram of subregions with borders of subregions

The MDV is a measurement of distance between two groups of numbers to find the similarity depending on calculating the distance between each value in the first group and the center of the second group [Geo92]. In this article, both groups represent the same set of the intensity values of the seed regions. Consequently, the MDV measures the distance between each intensity value of the seed region and the center of the same seed region. In Fig. 5, the first level of the distance could be measured by one range (from A to B). In contrast, the other levels of the distance have to be measured by two ranges (i.e. for the second level, the ranges are from C to A and B to D). Therefore, levels of MDV (except for the first level) consist of two ranges.

The suggested solution of this challenge is that the first level of the MDV will be chosen to be the reference subregion in each seed region. Figure 6 shows that both sides of the first level will be separated. Consequently, subregions which have the same MDV and different intensity values will be distinguished by the right and left side of the reference subregion.

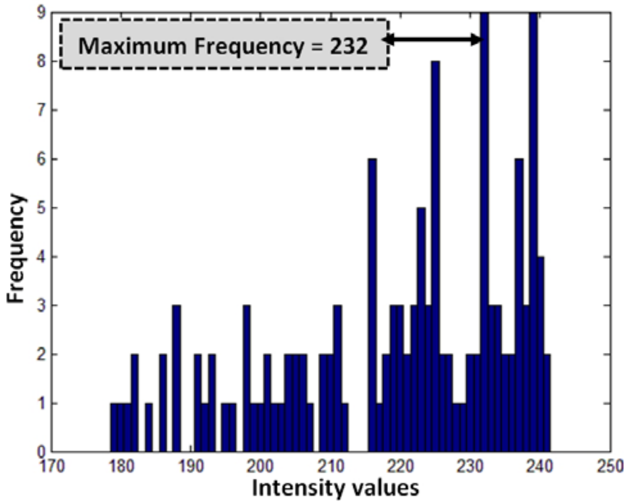


Fig. 7 The histogram of a subregion

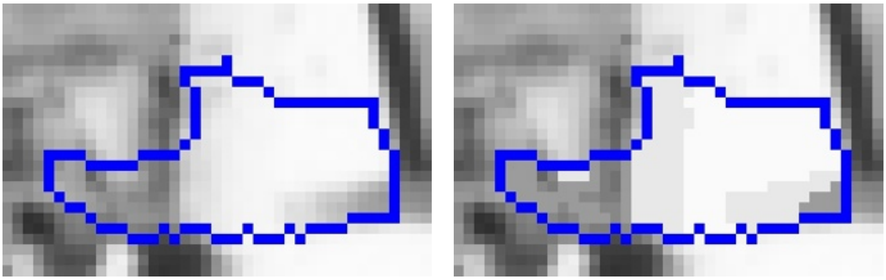
3.4 The Estimation Task

The main core of this step is to estimate a certain intensity value for each subregion of the historical aerial image. Therefore, each subregion will take a new intensity value which is relatively close to its previous intensity values but more clear and low gradient. The estimation process depends on a histogram process for determination of a new intensity values. In the histogram process, each subregion is represented as the histogram which is given as a discrete function [GW02, GEW04]:

$$H(R_k) = N_k, \tag{4}$$

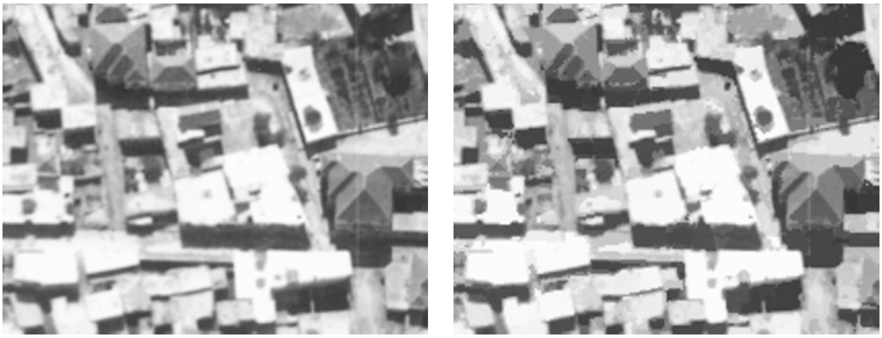
where:
R_k: *k*th intensity value, N_k: the number of the pixels in the image (with respect that those pixels have the intensity value R_k).

Figure 7 shows an example of the histogram which represents the reference subregion created in Sect. 3.3. Once the histogram is created, the intensity value R_k associated with the largest N_k will be selected to be the new intensity value of the subregion. The largest N_k has been selected because the intensity value, which has the largest frequency in the histogram, is often the representative color of the subregion.



(a) the seed region before enhancement (b) the seed region after enhancement

Fig. 8 A seed region is enhanced by MDV-based approach



(a) the historical image before the enhancement (b) the historical image after the enhancement process

Fig. 9 The whole historical image has been enhanced by MDV-based approach

4 Experimental Results

The final results of the MDV-based approach illustrate its ability to enhance the color objects in the historical images. In this context, a seed region before and after the enhancement process is depicted in Fig. 8. In addition, Fig. 9 shows the achieved results of the whole historical image of Baalbek.

These results are compared with results achieved by applying several special filters of the image enhancement. Figure 10a–d shows average, Gaussian, unsharp and disk filters supported by function *fspecial* in Matlab Software. In Fig. 10a, the average filter reduces the amount of the intensity variation of each pixel in the image. In contrast, the Gaussian filter is shown in Fig. 10b and it aims to remove the noise intensity values from the image. The third filter presented in Fig. 10c is the unsharp filter which enhances edges through subtracting the smooth image from the original image. Finally, Fig. 10d represents the disk filter which is a circular averaging filter with radius R. The radius value applied here is 5 [GW02, GEW04].

(a)

0,1111	0,1111	0,1111
0,1111	0,1111	0,1111
0,1111	0,1111	0,1111

(b)

0,0113	0,0838	0,0113
0,0838	0,6193	0,0838
0,0113	0,0838	0,0113

(c)

-0,1667	-0,6667	-0,1667
-0,6667	4,3333	-0,6667
-0,1667	-0,6667	-0,1667

(d)

0	0,0003	0,011	0,0172	0,011	0,0003	0
0,0003	0,0245	0,0354	0,0354	0,0354	0,0245	0,0003
0,011	0,0354	0,0354	0,0354	0,0354	0,0354	0,011
0,0172	0,0354	0,0354	0,0354	0,0354	0,0354	0,0172
0,011	0,0354	0,0354	0,0354	0,0354	0,0354	0,011
0,0003	0,0245	0,0354	0,0354	0,0354	0,0245	0,0003
0	0,0003	0,011	0,0172	0,011	0,0003	0

Fig. 10 Special filters supported by function *fspecial*; **a** the average filter, **b** the Gaussian filter, **c** the unsharp filter and **d** the disk filter

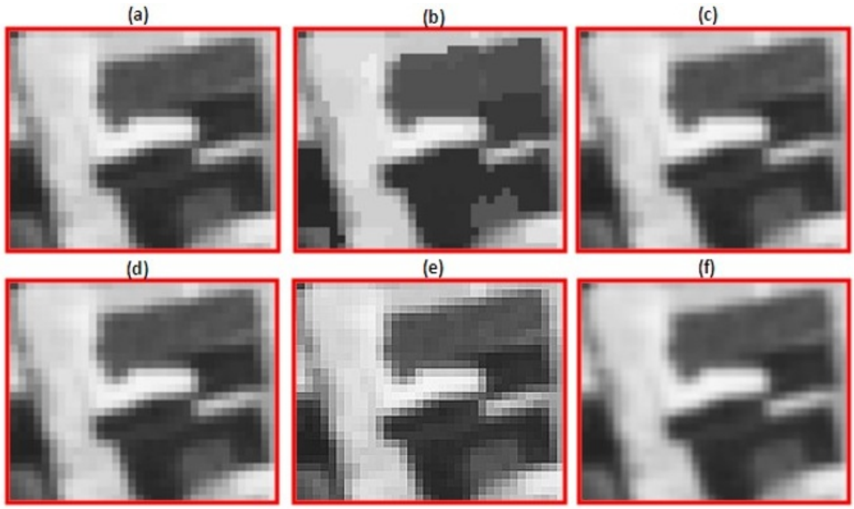


Fig. 11 Illustration of the comparison between the result of the MDV-based and other enhancement filters; **a** the original image, **b** the result of the MDV-based approach, **c** the result of the average filter, **d** the result of the Gaussian filter, **e** the result of the unsharp filter and **f** the result of the disk filter

Furthermore, the results achieved after applying the above-mentioned filters are depicted in Fig. 11a–f, where Fig. 11b shows that the MDV-based approach groups successfully the semi-similar intensity values. In addition, each partition is replaced by a new color which is relatively close to its original color but shows more clarity and low gradient. The noise intensity values are removed. In contrast, Fig. 11c–f shows that other filter could not replace the small partitions of the historical image by an intensity value.

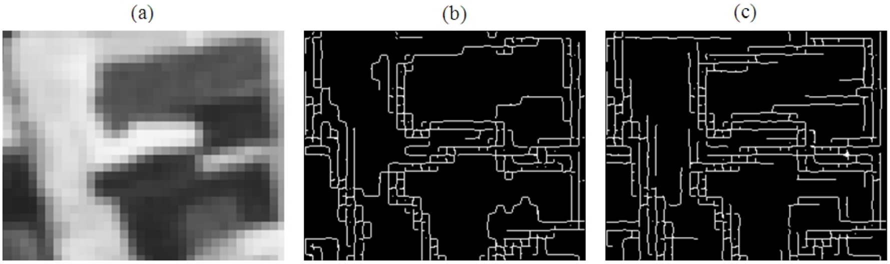


Fig. 12 The edge detection of a sample of the historical image before and after enhancement process; **a** the original image, **b** the edge detection after enhancement process and **c** the edge detection before enhancement process

In addition, Fig. 12 describes the effect of the MDV-based approach during the edge detection process before and after enhancement. The edges in Fig. 12b are more clear than the edges achieved without enhancement (cf. Fig. 12c). This confirms that the MDV-based approach enhances the detection process to be more accurate.

5 Conclusions

The MDV-based approach is introduced for appearance enhancement of objects in historical images of Baalbek. Within the MDV-based approach, a term "seed region" is defined for representing the semi-similar intensity values through a closed region. The MDV-based approach depends on the MDV for determining the distance of each intensity value in SR and the same set of IVs. As a result, the intensity values of these SRs will be redistributed into subregions. In addition, this redistribution enables the MDV-based approach to deal with partitions which are smaller than SR. Each partition is replaced by the intensity value which has the largest frequency associated with.

Each partition took a new color which is relatively close to the original color but more clear and low gradient. This leads to remove the noise intensity values from the partitions of the SR. Furthermore, the MDV-based approach allows the process of the objects detection to be more accurate. In future work, we aim to develop MDV-based approach to detect historical image objects. In this context, it will be geometrically proved how extent the detection process is sufficient and reliable. In other words, the geometric quality parameters (like the accuracy of points extracted which form for e.g. edges) should be taken into the account, because they take an important role in further applications (e.g. City Modelling).

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Longitudinal and Lateral Control in Automated Highway Systems: Their Past, Present and Future

Mohammad Alfraheed, Alicia Dröge, Max Klingender, Daniel Schilberg, Sabina Jeschke

Abstract Due to the increase in road transportation by 35 % over the last years in Europe it is essential to find solutions to optimize highway traffic. Therefore, several projects involving automated highway systems were initiated. In these systems, the longitudinal and lateral controls enable (with the help of other components) vehicles to be coupled electronically to form a platoon. Here, just the first vehicle is driven actively and the following vehicles are controlled automatically. Several projects were initiated to develop systems for different environments (i.e. Urban, Motorway). However, the developed techniques still are limited in their application range and e.g. cannot be applied in unstructured environment (i.e. rural or dirty areas). Furthermore, they were not tested for many different heterogeneous vehicles like trucks or passenger cars. This paper presents the past and present of automated highway systems and discusses solutions for future developments, e.g. how existing technologies can be adapted for a wider application range.

Key words: Automated Highway System, Unstructured Environment, Heterogeneous Platoon, Longitudinal and Lateral Control

1 Introduction

The optimization of national highway traffic has captured the attention of many governments, especially the European Union, for the reduction of the increasing number of the traffic jams and congestions. In 2003 the European Commission stated that every day 7500 kilometers of the European road system are being blocked by traffic jams [com06]. Furthermore, an increase of 55 % in road transportation is expected between the years 2000 and 2020 [com03]. To optimize highway traffic, vehicles

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are driven closely to each other with just the necessary safety distance. Each vehicle (except the first vehicle) is thus able to drive with a low air resistance, which saves energy and fuel. Moreover the number of congestions, the CO_2 emission and the global warming are reduced. [TK10] Several projects concerning Automated Highway Systems (AHS) therefore were initiated to optimize the highway capacity [KRHJ09, KTH09]. With AHS two homogenous vehicles are coupled electronically, meaning that each automobile is automatically controlled and driven at the same speed and safety distance [Shl08, veh10]. The longitudinal and lateral controls of AHS enable – with the help of other AHS components – vehicles to be coupled electronically and to form a semi-autonomous platoon. Therein the first vehicle is driven actively and the following vehicles automatically. The longitudinal control's essential function is the measurement of the distance between the preceding and following vehicle to maintain the safety distance. For the latter, the relatively constant speed of the preceding vehicle also has to be considered [KGAF10]. The lateral control's essential function is to keep the following vehicle behind the preceding vehicle. Two approaches are used for this task. The first is called "lane keeping", where the lane markings are considered as a reference point for the lateral guidance. The second is called "Electronic Two Bar", meaning that the relative position of each vehicle in the platoon is used to keep the following vehicle in the same track as preceding vehicle [Fri99]. As an example, the system developed within the research project KONVOI (Development and analysis of electronically coupled truck platoons) [KRHJ09, KTH09] is used to demonstrate the main components of AHS and the mechanism of the longitudinal and lateral controls.

1.1 The Platoon System Based on the Project KONVOI

The project KONVOI was funded by German's Federal Ministry of Economics and Technology as an interdisciplinary research project with partners of RWTH Aachen University, industry and public institutions. Generally KONVOI is established to optimize traffic flow with driver assistance systems.

In Fig. 1 the main components of the platoon system KONVOI are shown. An Advanced Driver Assistance System (ADAS) was developed to automatically control the longitudinal and lateral movement of the vehicles behind the actively driven preceding vehicle [KRHJ09]. A Light Detection and Ranging (LIDAR) distance sensor is used to measure the distance in longitudinal direction and the lateral offset to the preceding vehicle. The latter's track position, which is detected using a Complementary Metal Oxide Semiconductor (CMOS) image processing system, is used for the lateral control of the ADAS [KTH09]. Within the Adaptive Cruise Control (ACC) the target distance of 10 meters is realized. In addition, the ACC functionality has been improved based on the analysis of the data flow from the vehicle-vehicle communication via WLAN [KHR+10]. Therefore, a target acceleration interface is implemented in all platoon vehicles to automatically calculate the drive-train and the management of the different brakes. An automated guidance of

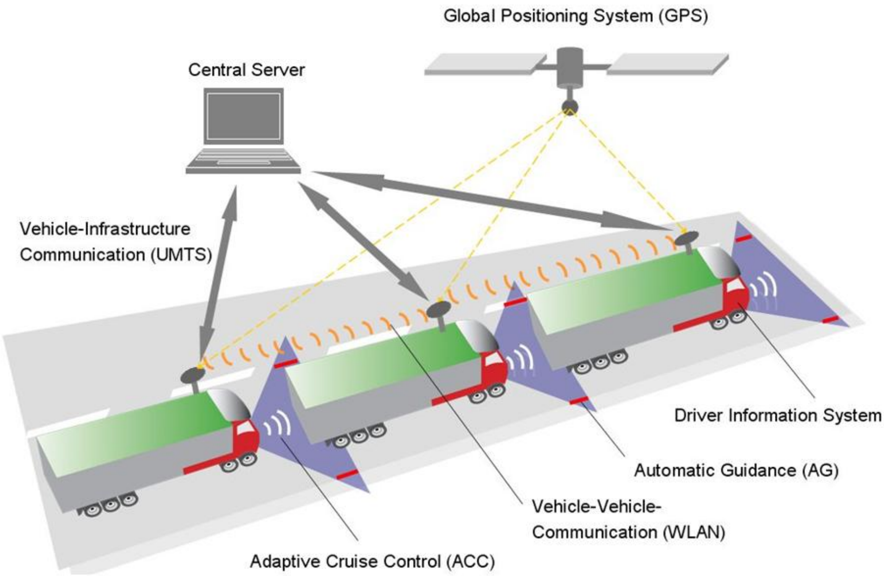

Fig. 1 The main components of the project KONVOI

vehicles is realized for the necessary steering moment based on a steering actuator which is established on the base of an electric motor and is built as a dual circuit with detached energy supply [RHG+09]. The Driver Information System (DIS) enables the vehicle driver to plan his route, select economic platoon participants as well as to initializes and confirms the platoon maneuvers. Moreover, the DIS sends the time schedule, route plan and GPS position of the vehicle with a vehicle-infrastructure-communication (G3) to the central server. The latter, in turn, organizes the platoon based on a data-mining-algorithm under consideration of economic aspects [PTK]. Within this paper a survey of AHSs is presented, which aims to give an overview about longitudinal and lateral control in different projects of AHS. Furthermore, the paper discusses possible solutions for future developments. An overview about the past and the present of AHS in Sect. 2 is given. The future developments of the AHS and what has prevented them so far for being used in non-highway environment are discussed in Sect. 3. The proposed solution for homogeneous vehicles and unstructured environment is given in the Sect. 4. Finally, the conclusion is presented in the last section.

2 The Past and Present of Automated Highway Systems

The PATH (Partners for Advanced Transit and Highways) project [Shl08, veh10] was initiated in California in 1986. Here, an automated platoon consisting of 4 cars was tested. The solution depended on radar sensors and one result was the reliable measurement of the lateral vehicle position. Another key result was that the cars maintained a fixed spacing of 6.5 meters between themselves while driving the platoon at highway speed. Within the DEMO 2000 project (the Demonstration 2000 Cooperative driving) [Tsu08, KTT+02], which was established by the Japanese Ministry of Economy, Trade and Industry in 2000, a system for obstacle detection was developed for longitudinal and lateral control. Within this development, the platoon is able to distinguish between small (i.e. small rocks) and big obstacles to drive around them. The development consisted of a dead reckoning vision system based on odometers [Tsu08]. The localization, heading and speed of each vehicle were transmitted via inter-vehicle communication based on 5.8 GHz DSRC (dedicated short-range communications). Recently, the DEMO 2000 project has developed the Energy ITS (Intelligent Transport System) which aims for the reduction of energy as well as of CO_2 emission [TK10]. Therein, three automated vehicles (25-ton trucks) are driven at 80 km/h with a 20 m inter-vehicle-distance. The longitudinal and lateral control depends on the vehicle-to-vehicle communication to transmit vehicle driving data (i.e. emergency braking and speed to other vehicles) as well as to enable merging and lane changing. In addition, the distance between vehicles is measured using triangulation between a pair of infrared markers on the top of the preceding vehicle. In the European project CHAUFFEUR I [Fri99], which was established in Germany in 1999, two homogeneous heavy vehicles were coupled. An onboard image processing system was used to determine the relative position of the preceding vehicle. This system depended on the detection of infrared light (IR) coming from IR emitters, which were attached to the back view of the leading vehicle. To avoid the requirement of special equipment in the preceding vehicle, the CHAUFFEUR II project (Germany, 2004) [FGSB04] developed the CHAUFFEUR assistant application. The longitudinal control system was provided by a radar system with data about the acceleration, distance and relative velocity of the preceding vehicle. The lateral control depended on lane markings, which were captured by a monocular camera [FGSB04]. The research project KONVOI [KRHJ09, KTH09, KHR+10, RHG+09], supervised by the Institute of Information Management in Mechanical Engineering at the RWTH, was started in 2005 in Germany. In KONVOI, an Advanced Driver Assistance System (ADAS) replaced the CHAUFFEUR assistant application to increase the efficiency and accuracy of the longitudinal and lateral controls [HLE03, KEJ03] Based on a requirement sheet [KEJ03, Pet06], which was developed especially for electronically coupled trucks, the developed ADAS had LIDAR distance sensors, CMOS-cameras and RADAR sensors incorporated. Four homogeneous trucks were equipped and electronically coupled so that a platoon was successfully formed at highway speed on a highway with a distance of 10 m between the vehicles. In KONVOI the coupled trucks were tested and realized in highway traffic for over 3000 km. Within the project PRAXITELE (Preliminary Results From the Saint-Quentin Station-Car Experiment) [DP96, LM99] a concept for individual public transport for urban environment was developed in France in 1999. Here a platoon of empty homogenous electric cars was realized. A heterogeneous scenario was not tested. The distance between the cars, the speed of every car and the angle between the preceding (the car in front) and the following car was determined for longitudinal and lateral control by a distance measuring sensor, velocity sensors and a vision approach that worked with a target located at the rear of each vehicle [DP96, LM99]. In 2004 the INRIA (Institut National de Recherche en Informatique et Automatismes) [LM99, Par04, PDLF05] patented a platoon technique with more advanced vision sensors, which did not depend on any additional equipment e.g. identical markers. This technique was developed in the CyberCar project [LM99, Par04, PDLF05] and depended on urban infrastructure. A heterogeneous scenario was not tested. Three approaches were demonstrated to achieve the longitudinal and lateral control of the vehicles. The first approach depended on a camera technique that extracted features from images of the preceding vehicle. The second approach used a laser scanner with reflective beacons. The third approach used a camera technique with IR emitters [LM99, Par04, PDLF05]. In 2009 the SARTRE (Social Attitudes to Road Traffic Risks in Europe) [car] project has been started by the Ricardo UK Ltd company. It uses a navigation system and transmitter/receiver unit that communicates with the preceding vehicle. First results are expected at the beginning of 2011. The system is to be developed for highways and heterogeneous vehicles.

3 Future: The Automated Highway System to be Developed

Traffic jam, congestion, CO_2 emission and the global warming do not only arise on highways, but also on unstructured environment (i.e. rural or dirty areas). Also, different shapes and types of vehicles are present on highway and unstructured environment. As shown in Table 1, all techniques developed within the projects discussed, were based on structured environment like a highway (see Sect. 2). In the future, the results of these projects should be also applicable to unstructured environment like e.g. for unpaved roads. Furthermore, these results should be adaptable for heterogeneous vehicles like passenger cars and trucks. Consequently, there is a need to apply the AHS on those environments without motorways. In addition, the need to merge different shapes of vehicles in the platoon for improving the optimization of the highway capacity.

In Fig. 2 the challenges, which need to be addressed to make AHS applicable in unstructured environment and for heterogeneous platoon are shown. They include the challenge (Weather Conditions), which arises due to in the proposed solution used equipment.

Challenge 1: Independence of Lane Marking

There are no lane markings in the unstructured environment (Fig. 2), but most AHS systems use lane markings as reference points for the lateral control in highway environment.

Table 1 Limitations of the significant projects of automated highway system

Project Name	Limitations
PATH	Limited to highway environment, since obstacles like rocks would deflect most of the sensors signals away from the follower.
DEMO 2000	Limited to short vehicle distances since platoon vehicles have to be in sight of each other to avoid the dissolution of the platoon.
CHAUFFEUR I	Limited to homogeneous vehicles, since the back view is not large enough to attach a large circular pattern of emitters to it.
CHAUFFEUR II	Limited to lane markings as reference points for the longitudinal and lateral control. No heterogeneous scenario was tested.
KONVOI	Limited to lane markings as reference points for the longitudinal and lateral control. No heterogeneous scenario was tested.
PRAXITELE	Limited to a short distance (around 5 m) between the cars.
CyberCar	Limited to expensive sensors and a short vehicle distance (2–15 m).
SARTRE	Limited to highway environment.

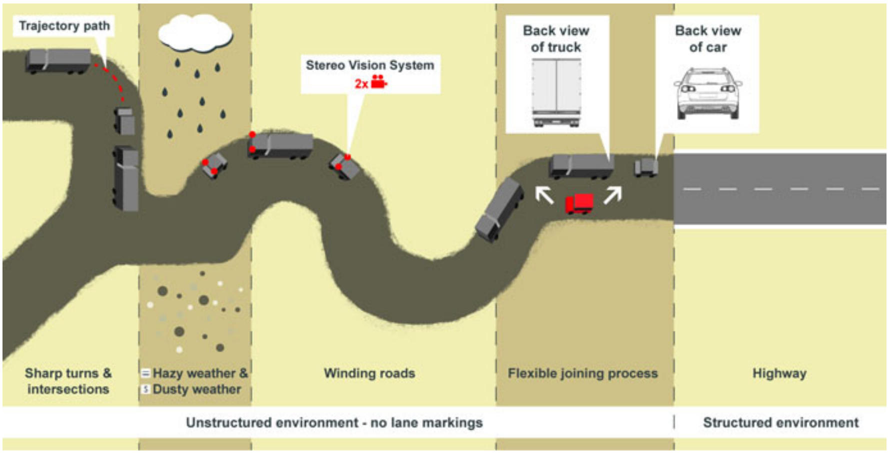

Fig. 2 Challenges to be addressed to apply the AHS in unstructured environment

Challenge 2: Flexible Joining Process

To realize heterogeneous vehicle convoys and to minimize the inter-vehicle-distance a flexible joining process is necessary. For example, in Germany the required maximum distance between cars relates to two tenths of their velocity [stv] e.g. 20 m for 100 km/h. The minimum distance from a truck to any kind of vehicle is 50 m. It therefore is much more efficient to drive passenger cars in a row, with smaller distances and the trucks in a row with a fixed distance of 50 m. Most developed AHS however only allow that a new vehicle can join the platoon at its front or end but not in the middle, which then would prevent the sorting of the vehicles by type.

Challenge 3: Platoon Dissolution in Winding Roads and Sharp Turns

Most of the AHS have dissolving problems, meaning that the platoon dissolves in winding roads because the preceding vehicle is just partly in sight of the following vehicle. Most of the signals therefore do not reach the sensors and thus the longitudinal control cannot work efficiently. Most systems are therefore limited to short distances between the vehicles. A similar challenge is the complete loss of the signal in sharp turns or when driving over a hill top or through a valley

Challenge 4: Weather Conditions

Due to the proposed solution (see Sect. 4), the dusty and hazy weather conditions reduce the image quality. Consequently, this challenge affects the efficiency of the distance measurement in the system because the appearance of the features of captured images is distorted.

4 Possible Solutions for Heterogeneous Platoons and Unstructured Environment

Within this work several solutions are proposed (Table 2) to overcome the addressed challenges (Sect. 3). An algorithm is proposed here, which is a combination of machine learning algorithm and tracking algorithm. The algorithm provides the longitudinal and lateral controls with the necessary parameters without using expensive equipment and infrastructure. For the controls the detection and tracking of the preceding vehicle is necessary, where the detection task depends on a machine learning algorithm. In contrast, for the tracking task a new mechanism is used to follow the preceding vehicle instead of detecting it again. Further, a stereo vision system (SVS) [stv, LSCVG08] is applied to measure the distance between vehicles.

Based on five issues, the proposed solution collection (SVS + BVPV) is compared to other available technical solutions, as shown in Table 3. These issues are the financial costs (Costs), the performance of the distance measurement (Performance), applicable under real time constraint (Reliability), robustness against hazy and dusty weather effects (Robustness) and compatibility with heterogeneous platoons and unstructured environment (Compatibility). Four available technical solutions are used for the comparison, which are an On Board Image Processing (IP) System with Infrared Lights (IR) [veh10, RHG+09][FGSB04, Pet06, LM99], Distance Measuring Sensors [Par04, PDLF05], Advanced Vision Sensors [Par04, PDLF05] and a Navigation System [TK10, car]. The here proposed solution is thus cheaper and shows a stable performance. The proposed solution still faces the challenge to be applied under real time constraints and to be robust enough in hazy and dusty weather. Furthermore, the solution has to prove its quality to be adaptable with the heterogeneous platoon and in unstructured environment.

Table 2 Proposed solutions to overcome the challenges addressed for heterogeneous platoon and unstructured environment

Challenge ID	Solutions Proposed to Overcome the Challenges
Challenge 1	Solving the lane marking dependency by using the back view of the preceding vehicle (BVPV) as a reference point.
Challenge 2	Realizing a heterogeneous platoon and the highway capacity optimization by the joining of a new vehicle where it fits best.
Challenge 3	Generating and saving the path of the preceding vehicle while driving the AHS on winding roads.
Challenge 4	Enhancement of the appearance of the captured back view.

Table 3 Proposed solutions to overcome the challenges addressed for heterogeneous platoon and unstructured environment

Tools	Costs	Performance	Reliability	Robustness	Compatibility
SVS + BVPV	Cheap	Very Good	No	No	Yes
On Board IP System with IR	Cheap	Good	Yes	No	No
Distance Measuring Sensors	Expensive	Excellent	Yes	Yes	No
Advanced Vision Sensors	Expensive	Excellent	Yes	Yes	No
Navigation System	Expensive	Excellent	Yes	Yes	Yes

5 Conclusion

The longitudinal and lateral movement of a platoon of vehicles can be controlled and automated with suitable equipment ("Automated Highway Systems"). However, existing approaches are based on the capture and evaluation of lane markings and therefore are not applicable in an unstructured environment. Also, they are optimized for homogeneous convoys. Based solely on the information acquired by a Stereo Vision System a solution is proposed which controls the longitudinal and lateral steerage for unstructured routes as well as heterogeneous convoys. The central challenges are: 1) Independence from lane markings, 2) Handling of signal loss in sharp turns, 3) Stability with reduced image quality (weather conditions), 4) Control of heterogeneous convoys (vehicles of different type), 5) Capability to integrate further vehicles into the platoon flexibly. The back view of the preceding vehicle is used as a starting point for the solution: Based on vehicle distances and deviation angles of different reference points of the preceding vehicle, its further trajectory path is calculated and the steerage of the vehicle automatically adapted. The solution thus allows the extension of automated highway systems to a manifold of additional application scenarios.

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Real Time Detection of the Back View of a Preceding Vehicle for Automated Heterogeneous Platoons in Unstructured Environment Using Video

Mohammad Alfraheed, Alicia Dröge, Ralph Kunze, Max Klingender, Daniel Schilberg, Sabina Jeschke

Abstract Due to the increase in road transportation several projects concerning automated highway systems were initiated to optimize highway capacity. In the future, the developed techniques should be applicable in unstructured environment (e.g. desert) and adaptable for heterogeneous vehicles. But before, several challenges, i.e. independency of lane markings, have to be overcome. Our solution is to consider the back view of the preceding vehicle as a reference point for the lateral and longitudinal control of the following vehicle. This solution is independent from the environmental structure as well as additional equipment like infrared emitters. Thus, both the detection and tracking process of the back view are needed to provide automated highway systems with the distance and the deviation degree of the preceding vehicle. In this paper the first step, the detection and location of the back view on video streams, is discussed. For a definite detection in a heterogeneous platoon several features of the back view are detected. A method is proposed to run rejection cascades generated by the AdaBoost classifier theory on the video stream. Compared to other methods related to object detection, the proposed method reduces the running time for the detection of the back view to 0.03–0.08 s/frame. Furthermore, the method enables a more accurate detection of the back view.

Key words: Real Time Detection, Automated Highway System, Unstructured Environment, Machine Learning

1 Introduction

Over the last years road traffic has increased by 35 % in Europe [KRHJ09] and thus also the demand to optimize highway capacities. Therefore, several projects concerning Automated Highway Systems (AHS) were initiated [KRHJ09, KTH09].

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With AHS two homogenous vehicles are coupled electronically in order to optimize the highway capacity [Shl08, veh10]. All developed techniques are based on structured environment like e.g. a highway. An application of the developed techniques in unstructured environment and with heterogeneous vehicles, like passenger cars and trucks, would extend the application range of these AHS to automated heterogeneous platoons.

Several challenges prevent the developed systems to be applied in unstructured environment like e.g. in a desert. Some of these challenges relate to the unpaved environment, such as no lane markings. Other challenges arise due to winding roads or sharp turns, where the signal from the preceding vehicle gets lost and the platoon dissolves.

The first AHS project, the PATH project, run from 1992 to 2003 and was based on radar sensors [Shl08, veh10], which enable a detection system to measure with high accuracy. The drawback was that the following vehicle detected also benign obstacles (i.e. small rocks). Therefore, the DEMO 2000 project a system for the detection of obstacles was developed to recognize such obstacles [KTT+02, Tsu08]. This system however required the platoon vehicles to be in sight of each another, which is not fulfilled in sharp turns or hidden intersections. The CHAUFFEUR I project [Fri99] used an onboard image processing system to determine the relative position of the preceding vehicle. This system depended on the detection of the infrared light (IR) emitters attached to the Back View of the Preceding Vehicle (BVPV). However, within CHAUFFEUR I the vehicles also had to be in sight of each another [Fri99]. Not all back views however are suitable to have IR emitters attached to them, because the involved vehicles in the platoon are heterogeneous vehicles (either truck vehicles or passenger cars) and the back of a car is not large enough to attach a large circular pattern of emitters to it. The emitters are also an additional cost factor. To avoid the requirement of special equipment for the preceding vehicle, the CHAUFFEUR II project developed the CHAUFFEUR assistant application [FGSB04]. In contrast, the KONVOI project of IMA/ZLW & IfU [KRHJ09, KTH09, RHG+09, KHR+10, FHH05] developed an advanced driver assistance system (ADAS) controlling the longitudinal and lateral adjustment. This system was based on Light Detection And Ranging (LIDAR) and radar sensors. However, both systems are not applicable in unstructured environments, because they use infrastructure based information like lane markings as references for the longitudinal and lateral control. In the PRAXITELE project [DP96, LM99], a platoon of empty homogenous electric cars was developed for urban environment use. Here however, the distance between the cars had to be small (ca. 5 m). In addition, the cars had to be equipped with identical markers. To overcome these limitations, the INRIA (the Institut National de Recherche en Informatique et Automatismes) as supervisor of the PRAXITELE project patented a platoon technique with more advanced vision sensors in the CyberCar project [LM99, Par04, PDLF05]. Despite the successful results achieved therein, the system still depends on expensive sensors.

The solution discussed in this paper offers a part-solution (since only the detection process without tracking is considered) to adapt AHS to unstructured environment. Emphasis lies on the development of a less technical intensive and less expensive solution meaning without radar and LIDAR technology. Though the latter is more accurate than a SVS it cannot identify the target object independently. Furthermore, the platoon considered here can also incorporate heterogeneous vehicles; where before only platoons with comparable to similar vehicles were considered.

The basis is to consider the BVPV as a reference point for the lateral and longitudinal control. Both controls use features of the BVPV instead of fixing special tracker onto it or using lane markings as a reference points. Both processes, the detection and tracking of the BVPV, provide the AHS with the distance and deviation degree of the preceding vehicle. Further, the trajectory path of the preceding vehicle is calculated, which enables the system to track a disappearing preceding vehicle.

In this paper the starting process – the detection of the BVPV – is discussed using video streams, which show a preceding vehicle driven on an unstructured environment. The detection task needs to be able to determine several different features of the back view in order to work with a heterogeneous platoon. In addition, the detection task has to be applicable under real time constrains. The main challenge of this task is that the BVPV is not standardized and is different for each vehicle. For instance, the preceding vehicle could be a passenger car, urban truck or military truck. Additionally, the dynamic environment represents another challenge for the detection of the back view, since the dynamic view often changes the appearance of the back view of the vehicle.

Already published methods for object detection and tracking [Rob09, LTZL09] rely on the background subtraction technique, which is applied to subsequent frames captured by a stationary camera. With these approaches, useable features can be extracted successfully for tracking and detection. However, these techniques are not useable for a moving camera due to large-scale background changes [BK08]. Okuma et al. [OTF+04] extended particle filters to multi-target tracking for a changing background, in this case moving hockey players. Moreover, they proposed a probabilistic mixture model to incorporate information achieved from AdaBoost – it is a machine learning algorithm and it is used for feature selection and classification [BK08] – and the dynamic model of the individual object. The latter measures the similarity of the color histogram based on statistical properties and estimates the tracker region of the interested object. The main drawback is that the dynamic model cannot be applied in AHS because the color of the object of interest cannot be distinguished from the environment.

Grabner et al. [GB06] therefore proposed a novel on-line AdaBoost feature selection method which is able to tackle a large variety of real time tasks (i.e. learning complex background model, visual tracking and object detection). With their method the discrete AdaBoost algorithm [Sch01] is used for feature selection and classification. To classify the foreground (object of interest) and background, they partition the image into small blocks. The classifier associated with each block classifies it as foreground and background region. The latter is a statistical predictable block in the image, but the former is unpredictable. The method described in this paper distinguishes itself from both, the extended particle filters and the on-line boosting method, through its ability to detect the BVPV without the need to estimate or detect the background regions. Moreover, the method considers the expected size of the object of interest.

Compared to the "HaarDetectedObject" method, which is implemented in the OpenCV library and functions as a single agent to detect the human face [fac10], the method described distinguishes itself by the reduction of the running time needed for the detection of the back view. Furthermore, the method enables a more accurate detection of the BVPV. Therefore, the method analyzes the output of one expected back view size instead of considering outputs of all sizes. In case that there are more than two detected back views the time needed to classify them is saved and the next frame processed.

To realize the detection of the back view several steps have to be carried out. First, positive and negative data have to be acquired (Sect. 2.1). Next, several classifiers are generated to classify both kinds of data from each other based on the AdaBoost algorithm (Sect. 2.2). The modifications of the method implemented in an OpenCV Library are presented in Sect. 2.3. With these classifiers the data is tested to figure out whether the incoming data shows an interesting object or not (Sect. 3). Finally, a conclusion is given (Sect. 4).

2 Realization of the Back View Detection

A single agent is required to learn and detect the BVPV based on the machine learning algorithm. The rejection cascades generated in the training step of the single agent are passed to the testing section for detecting BVPV. The single agent in turn detects features, which detect the BVPV from the environment as well as for different shapes of vehicles. In the following sections the realization of the back view detection are described in more detail.

2.1 Data Acquisition

The AdaBoost algorithm is used to generate the cascade of the stronger classifiers. It therefore needs training data (positive and negative images). The positive image data represents the desired object, whereas the negative image data represents the environment. Furthermore, the collected data has to include several back view shapes of possible preceding vehicles. To acquire data, different back views were taken from video streams. Figure 1 shows samples of positive images (Fig. 1a) and negative images (Fig. 1b).

2.2 The Algorithm to Train the Data

The real time detection of the back view is difficult since the considered scene is not static but always changing during driving. Thus, the intensity values of objects and

(a) samples of positive image data (b) samples of negative image data

Fig. 1 Training data examples

a b c d e f g

Fig. 2 Samples of selected features from heterogeneous vehicles and external environmental effects: **a** passenger car, **b** bus, **c** van, **d** caravan, **e** truck, **f** sunshine reflection, **g** darkness

background features change depending on the environment. Moreover, the appearance of the back view also changes, because the distance between the BVPV and the camera used to capture video streams varies. Therefore, features from vehicles close to each other are clearer than features from distant vehicles. A machine learning algorithm is used to perform the detection process, since it has proven its quality when used in real time object detection applications [BK08, vio].

Because of the required high performance in real time object detection, the AdaBoost algorithm is used to generate the rejection cascade and to train the data. Both positive and negative images have to undergo a training process to generate classifiers. The strongest classifiers generated from AdaBoost Algorithm enable the detection and location of the BVPV in the dynamic environment.

Several strong classifiers are required, which are precise enough to separate both features of the BVPV and features of surrounding objects. In this paper, the “Haar-Like” Features [GB06, vio, LM02] are used to enable these classifiers to detect the BVPV.

The training part of the AdaBoost algorithm is run on a Linux operating system (on a PC with a 2 GHz Intel Duo Core CPU and 3 GB memory). The strongest classifiers generated from the training process are stored as a cascade. In this context, the cascade is a memory structure of the AdaBoost training stages. In each stage several strong classifiers are generated (based on their “Haar-Like” features), which are used to estimate if the input frame contains an object of interest or not.

To realize a heterogeneous platoon, several features are extracted by the training part of the AdaBoost. In our case the number of the used features is larger than 500. Figure 2 shows samples of these features for heterogeneous vehicles. Moreover the training part extracts the appropriate features of the back view in order to adapt to external effects of the environment. The effects presented are sunshine reflection towards the camera as well as when a back view is captured in the darkness. Figure 2 also shows extracted features for both those effects. Despite of the main features of the back view are being hidden by these effects, the training process successfully

Table 1 Output parameters of the training algorithm for the generated cascade

Parameter name	Value	Description
Experiment Error	1.04701e−07	The false choices i.e. positive images recognized as negative and vice versa
Hit Rate	87 %	The percentage of the right choices for the positive data
Background Processing Time	547202 s	The time consumed to calculate the False Alarm Rate
Training Completion Time of stage 30	2981 s	The time consumed to complete the training stage

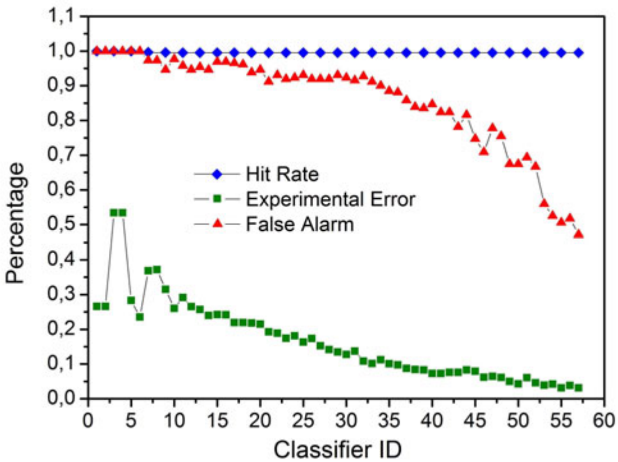

Fig. 3 Hite Rate, Experimental Error and False Alarm for each classifier in stage 30

extracts other features. Consequently, the rejection cascade works efficiently for different vehicle types and in a changing environment.

To show the accuracy achieved with the training algorithm the output parameters of the training algorithm from stage 30 are presented in Table 1.

Figure 3 shows the most significant parameters, which delivered satisfying results obtained with the training algorithm. As can be seen the number of classifiers is 57 for stage 30 (the last stage in the generated cascade). The Hit Rate of these classifiers is approximately 100 %. In contrast, the False Alarm Rate ranges from 50 % to 100 %. In other words, with these classifiers one can detect the interested object (BVPV). But they can also detect similar features in the negative data. This is normal, because classifiers work with the addition and subtraction of the intensity values among rectangle areas. Consequently, the same value of the rectangular area might be found in both negative and positive image data. The experimental error represents false choices for positive and negative data. The Experimental Er-

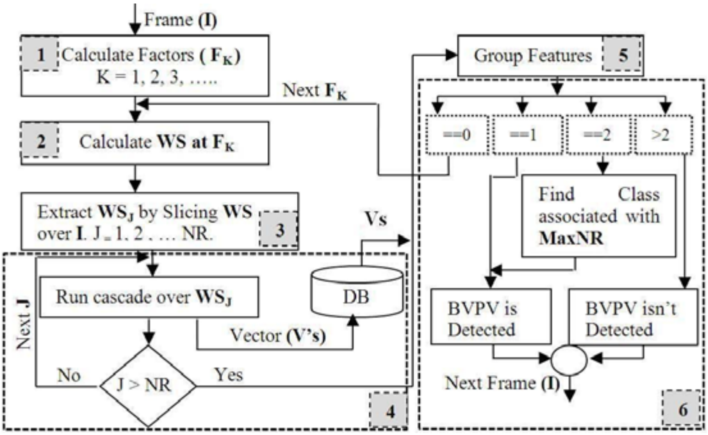

Fig. 4 Flowchart of the approach

ror achieved for the whole cascade is low (1.04701e−07), which proves that the accuracy is high enough to classify features of positive and negative data [BK08].

2.3 The Modified Method to Test the Data

A single agent is required to learn and to be able to detect the BVPV based on a machine learning algorithm. The rejection cascades generated by the training section of the single agent are passed to the testing section to detect the BVPV. The single agent, in turn, detects features which distinguish the BVPV from the environment. Usually, the detected features represent the BVPV as well as semi-similar BVPV (e.g. the front view of vehicles). To prevent this, an already developed "HaarDetectedObject" method [fac10] is modified to run rejection cascades generated by AdaBoost algorithm on the video stream. Figure 4 shows the flowchart of the approach. In the following, the single steps of the flowchart are explained in more detail.

2.3.1 Reception of the Image (*I*) of the Video Stream

At the beginning, the Factor F_K is calculated based on (1). The Factor F_K represents coefficients of the expected sizes in the frame. With these coefficients the different size of BVPV in the current frame are measured

$$F_{K+1} = F_K \times S, \quad K = 1, 2, 3, \ldots, \tag{1}$$

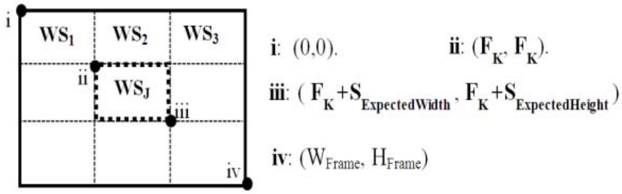

Fig. 5 Cutting-off mechanism

where S is the increment coefficient. The maximum number of factors K is achieved when the following condition (2) is satisfied:

$$F_K \times W > W_{\text{Frame}} \quad \text{and} \quad F_K \times H > H_{\text{Frame}} \tag{2}$$

with W being the minimum assumed width of the object of interest, H, the minimum assumed height of the object of interest, W_{Frame} the width of current frame I and H_{Frame}, the height of current frame I.

2.3.2 Calculation of the S_{Expected} at the F_K

The expected size S_{Expected} of the BVPV is calculated based on (3), (4) and (5), where $S_{\text{ExpectedWidth}}$ is the expected width and $S_{\text{ExpectedHeight}}$ is the expected height. This step is the beginning of the loop $NextF_K$ which determines the expected sizes of the BVPV. The initial value of the F_K is the maximum number of factors. In other words, the Loop $NextF_K$ starts from the maximum value of the generated F_K which leads to the maximum size of S_{Expected}. The main reason behind this selection is that the distance between the preceding and the following vehicle lies between 5 to 10 meters at the formation of the platoon (here the point of this formation is assumed). Within this method the maximum size possible of the BVPV is searched for at the beginning. Within this step the method considers the expected size of the interested object.

$$S_{\text{Expected}} = \{S_{\text{ExpectedWidth}}, S_{\text{ExpectedHeight}}\}, \tag{3}$$

$$S_{\text{ExpectedWidth}} = F_K \times W, \tag{4}$$

$$S_{\text{ExpectedHeight}} = F_K \times H. \tag{5}$$

2.3.3 Extraction of WS_{J} by Cutting WS out of (I)

The image WS_{J} corresponding to S_{Expected} from the current frame is extracted by slicing the S_{Expected} over the current Frame I. The slicing mechanism is shown in Fig. 5. Many images WS_{J} are extracted from the current frame so that J is the index of these images. Therefore, a loop $NextJ$ is started at this point to check the WS_{J}.

2.3.4 The Loop *NextJ*

Inside the Loop *NextJ*, the rejection cascades are used to check whether the WS_J shows BVPV or not. If a BVPV is detected, the vector *V* is stored in the DataBase DB in order to be processed later. The vector V has two parameters. The first parameter is DetectedFeatures which includes the coordinates of the detected features associated with the WS_J. The second parameter is WS_J which includes the coordinates of the WS_J.

2.3.5 *GroupFeatures*

At the end of the loop $Next_J$, the vectors *V* are retrieved from the *DB* and passed to the step GroupFeatures. The goal of the step *GroupFeatures* is to group *WS* together to facilitate the detection process of the BVPV. In the step GroupFeatures the detected WS based on the distance among them are grouped together. As a result, these detected WS are clustered into many classes. The output parameter *NClasses* represents how many classes are generated from the step *GroupFeatures*.

2.3.6 *NClasses*

The *NClasses* "0" represents the case if the number of detected *WS* is 0 or 1. Therefore, the grouping is not possible and the BVPV cannot be detected immediately but possibly with the next Factor FK-1. The next possible value of the NClasses is "1", meaning that the approach detects the BVPV. The third value is "2". As for this value, the approach considers the class with the maximum number of *WS* as the BVPV. The loop stops if $NClasses > 2$ to prevent extra-long running times, since the BVPV can be detected rapidly in the next frame. Within this step, the approach analyzes the output of one expected back view size instead of considering outputs of all sizes. In addition, the approach saves the time needed to classify them and then process the next frame. The approach thus reduces the running time for the detection of the back view. Furthermore, the method enables a more accurate detection of the BVPV.

3 Results of Experiment and Discussions

The experiments are performed using our non-optimized implementation and run on a PC with a 2 GHz Intel Duo Core CPU. The achieved results are compared with other methods related to object detection. Experiments show that the number of features is larger than 500, meaning that over 500 features to detect several shapes of the back view of a heterogeneous platoon are obtained.

Satisfying results with the modified method are obtained (see Table 2). Figure 6 shows the achieved results for different distances of the preceding vehicle as well as

Fig. 6 Samples of the (un)successful results based on the proposed approach. Successful results (**a**, **b**, **c**) and unsuccessful results (**d**, **e**, **f**)

Table 2 Output parameters of the training algorithm for the generated cascade

Parameter name	Scenario 1	Scenario 2	Scenario 3
D_{Total}	92.5 %	94.06 %	94.7 %
D_{BackView}	81.14 %	88.12 %	94.7 %
$D_{\text{FrontSide}}$	11.59 %	5.94 %	0 %
$D_{\text{UndesiredObject}}$	3.18 %	5.94 %	4.2 %
D_{Failed}	4.09 %	0 %	1.1 %
Number of Frames	440 %	101 %	1301 %

for different vertical positions of BVPV. However, the proposed method also fails to detect the BVPV in some situations (see Fig. 6). The main reasons are: firstly there are sometimes semi-similar detected features, which are closer than the BVPV (see Fig. 6e). Secondly, the BVPV is not detected in the captured frame (see Fig. 6d). Thirdly, the distance between BVPV and camera is larger than 10 meters, whereas the algorithm is designed to work between 5–10 m.

The approach is tested with over 1800 frames taken from a video stream captured by the Artificial Vision and Intelligent Systems Laboratory (VisLab) of Parma University in Italy [art10]. Values of the significant parameters are shown in Table 2 based on different scenarios. The scenarios in this work represent different positions of the BVPV. Scenario 1 (see Fig. 6a) includes those frames where the BVPV is moving with a distance of 5–10 m and is surrounded by semi-similar back views (i.e. side view of the vehicle). Scenario 2 (see Fig. 6b) includes the environmental effects on the captured back view. These effects are due to winding turns and reflection of the sunshine towards the camera. Scenario 3 (see Fig. 6c) merges scenario 1 and 3 together except for the semi-similar back view.

As shown in Table 2 the success rate for the tested frames D_{Total} is arithmetic average 93.8 % based on different scenarios. It is calculated by adding the percentage of the back view detection $D_{BackView}$ to the percentage of the detection of the other vehicle sides $D_{\text{FrontSide}}$. The latter is considered as a successful detection because those sides have sometimes the same features of the back view and the described method detects them successfully. But this kind of detection (as shown in Fig. 6e) does not satisfy this work's aims. Therefore, this rate is considered later as false detection (see Fig. 7). The percentage of unsuccessful results considers the detection of undesired objects $D_{\text{UndesiredObject}}$ or the detection of more than two objects (D_{Failed}) as shown in Fig. 6d, f respectively.

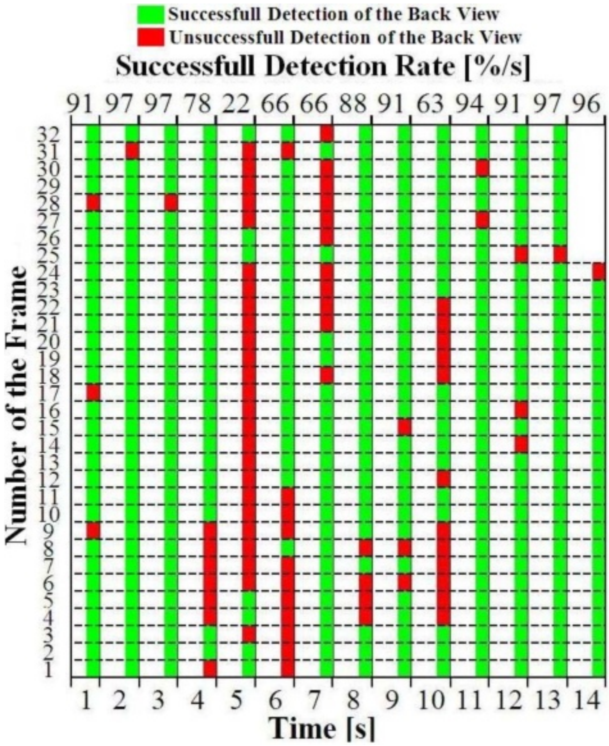

Fig. 7 A demonstration for (un-) successful detection of the back view using frames associated with scenario 1

The percentage is reduced since the unsuccessful detection is replaced by the next successful result obtained with the previous or next frame. To explain this fact the number of frames (440) associated with scenario 1 are re-organized as 14 subgroups (seconds). Each subgroup or second contains 32 frames as shown in Fig. 7. The reason behind the selection of 32 frames is to simulate the normal speed of the video stream, which is usually measured by 32 frames/s. The unsuccessful results ($D_{\text{FrontSide}}$, $D_{\text{UndesiredObject}}$ and D_{Failed}) were marked as red (dark grey). In case the proposed method detects the back view, the frame is highlighted as green (light grey). Other frames marked as successful detection could be used to replace the unsuccessful results. Thus, the achieved results are reliable when the BVPV is about 5 to 10 meters away from the camera.

The running time achieved with the experiments (0.03 to 0.089 seconds) shows that the method is able to work under real time constraints. This test was also carried out for scenario 2 and 3. The results were similar to the one from scenario 1 showing that the algorithm can be used for different traffic situations.

In future work, the distance between the following and preceding vehicle will be measured. The results will be published elsewhere. In this case therefore, the relationship between the running time and the detection of the back view is esti-

Table 3 Output parameters of the training algorithm for the generated cascade

Resolution (pixel)	Region Determination	Processor Speed (GHz)	Scenario 3	Running Time
Proposed Method	No	2.00	752×480	12–30 frames/s
On-line Boosting	Yes	2.80	384×288	15–20 frames/s
Boosted Particle Filter	Yes	1.60	–	$\approx 1/2$ frames/s
HaarDetectedObject	No	2.00	752×480	1/28 frames/s

Fig. 8 Comparison between the "HaarDetectedObject" method (*left*) and the presented method (*right*)

mated based on the detected size, instead of the vehicle distance. 200×200 pixels represent approximately 10 meters. Consequently, the running time lies around 12–30 frames/s.

The results are compared with Boosted particle Filter, On-line Boosting and "HaarDetectedObject" methods. Table 3 shows that the comparison depends on four variables. (*The data of the second and the third row is extracted based on the already published corresponding publication* [OTF$^+$04, GB06].) The first parameter (Region Determination) can take two different values (yes or no). If the method determines the region that most likely contains the object of the interest the value is yes. The second parameter (Processor Speed) is the processor speed which is used to run the method. The third parameter (Resolution) represents the dimension of frame used within the methods. Finally, the last parameter represents the running time needed to detect the object of interest. As shown in Table 3 the described method distinguishes itself from others through the detection of the back view without estimation of the object region, using a normal processor and adapting with the highest resolution as well. Moreover, the proposed method processes the frame faster than the other discussed methods.

Regarding the "HaarDetectedObject" method implemented in OpenCV to detect faces [Sch01], Fig. 8 shows that the proposed method detects the BVPV more accurate than the "HaarDetectedObject". Moreover, our approach works under real time constraints since the running time lies around 0.03 s. In contrast, the "HaarDetected-Object" approach requires around 28 s to apply the rejection cascades.

4 Conclusion

Several challenges were discussed, which prevent current automated highway systems to be applied in unstructured environment. A method was presented, where the Back View of the Preceding Vehicle (BVPV) is used as a reference point for the longitudinal and lateral controls. This approach was tested with over 1800 frames. Successful results were achieved for around 93.8 % of them. Problems occurred for distances larger than 10 meters between BVPV and camera, when semi-similar detected features are closer to the camera as the BVPV and the latter was not detected in the captured frame. The experiments show however, that the number of features to successfully detect a BVPV was larger than 500. This proves that with this approach several shapes of the back view of heterogeneous platoons can be detected. This approach distinguishes itself from other methods by its ability to detect the BVPV. Moreover, it allows working under real time constraints, because the running time lies around 12–30 frames/s. In future work, we aim to develop the approach further to increase its reliability through tracking the back view under real time constrains. In addition, the development will focus on generating the historic path of the detected object in order to estimate the expected location of the back view. It also will be tested whether this approach is suitable for different camera systems, such as infrared and high resolution cameras.

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Artificial Cognition in Autonomous Assembly Planning Systems

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Abstract Cognition is of great interest in several scientific disciplines. The issue is to transfer human cognitive capabilities to technical systems and so generate artificial cognition. But while robots are learning to communicate or behave socially only a few examples for applications in production engineering and especially in assembly planning exist. In this field cognitive systems can achieve a technological advance by means of self-optimization and the associated autonomous adaption of the system's behavior to external goal states. In this paper cognitive technical systems and their software architectures in general are discussed as well as several assembly planning systems. A precise autonomous assembly planning system and its implementation of cognitive capabilities is presented in detail.

Key words: Cognition, Self-Optimization, Cognitive Technical Systems, Assembly Planning Systems

1 Introduction

Nowadays, due to shortening product life-cycles and changing customer demands manufacturing and assembly systems should be flexible to quickly react to changes in products and their variants. Highly automated manufacturing systems therefore tend to be neither efficient enough for small lot production nor flexible enough to handle products to be manufactured in a large number of variants. To increase flexibility *"future manufacturing systems should focus on the integration of the human*

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operator … due to his or her extraordinary problem solving abilities, creativity and sensorimotor skills" [SRL02]. Based on simulated cognitive functions, technical systems shall not only be able to (semi-) autonomously derive manufacturing planning, adapt to changing supply conditions and to learn from experience but also to simulate goal-directed human behavior and therefore significantly increase the systems flexibility. These systems offer the possibility to generate effective, efficient and finally self-optimizing joint cognitive systems [ZW08].

In this paper, cognitive technical systems (CTS) and their software architectures as skeletal structure for artificial cognition are presented. Following a definition of the terms *cognition* and *self-optimization* several architectures and approaches are discussed. The focus is on cognitive assembly planning systems. Within the Cluster of Excellence "Integrative production technology for high-wage countries" at RWTH Aachen University, basics for a sustainable production-scientific strategy and theory, as well as for the necessary technological approaches are developed[1]. In the research field "Self-optimizing Production Systems", the project "Cognitive Planning and Control System for Production" develops and implements such a cognitive assembly planning system which is presented in Sect. 4. Furthermore, the way of realization of cognitive capabilities in this technical system is shown.

2 Definitions

2.1 Cognition

The term *cognition* is defined inconsistent and in a predominant human-centered perspective in literature. Within the field of psychology several definitions are applied. A popular definition is the one of Matlin [Mat08], who describes cognition in this context as acquisition, storage, transformation and use of knowledge. Thereby the term knowledge is to be understood as an aggregation of information which is related to a human. Strohner [Str95] extends the term to technical systems and defines cognition as *"… any kind of information processing by the central nervous system of a human or an appropriate information processing in artificial systems…"*. With regard to technical systems cognitive capabilities which are necessary to build up the processes aforementioned are (1) perception, (2) reasoning, (3) remembering, (4) planning, (5) decision making, (6) learning and (7) action [ZG05, LLR09].

Perception presents the process of including sensory data and its processing and aggregation to information. It is realized by a continuous observation of the system itself and the environment and can also involve the integration of results from different modalities into a single assessment [LLR09]. **Reasoning** describes the transaction of augmentation of knowledge from already present knowledge and

[1] The authors would like to thank the German Research Foundation DFG for supporting the research on human-robot cooperation within the Cluster of Excellence "Integrative Production Technology for High-Wage Countries" at RWTH Aachen University.

the assumption about the environment involved through inductive and deductive reasoning. **Remembering** is the ability to encode and store the results of cognitive processing in memory and to retrieve or access them at a later point in time [Str98]. **Planning** usually refers to cognitive activities within the human's respectively agent's head. A plan is generated which is than represented as a set of actions [BBB+11]. Thus planning is the basis for **decision making** in which a decision is derived matching the goal state which furthermore generates an adequate behavior.

An important cognitive capability is the process of **learning**. Out of the experiences and the sensory information new behavior patterns and knowledge can be derived. This augmentation of knowledge differs from that through reasoning, where tacit knowledge is made aware while the process of learning generates entirely new knowledge [Mat08]. Finally, **action** comprises the realization of the capabilities aforementioned by actively manipulating the environment.

The impact on cognitive technical system and its structure and implementation is explained in Sect. 3.

2.2 Self-Optimization

The term *self-optimization* is defined in a convincing way by the Collaborative Research Centre 614 "Self-optimizing concepts and structures in mechanical engineering" (CRC 614) at the University of Paderborn, Germany [Col]:

> Self-optimization describes the ability of a technical system to endogenously adapt its objective regarding changing influences and thus an autonomous adaption of the system's behavior in accordance with the objective. The behavior adaption may be implemented by changing the parameters or the structure of the system. Thus self-optimization goes considerably beyond the familiar rule-based and adaptive control strategies; Self-optimization facilitates systems with inherent "intelligence" that are able to take action and react autonomously and flexibly to changing operating conditions.

The process of self-optimization can be divided into three distinct steps [FGK+04]:

1. **Analyzing the current situation**: The current situation contains the system's state and the relevant information from the environment as well as stored information from previous observations. These pieces of information can also be picked up by communication with other systems (human or technical). This step includes the analysis of the achievement of the objectives given by the operator or other technical systems.
2. **Determining the system's objectives**: During the determination, new system's objectives can be created by generation, adjustment or selection. Selection results from a predetermined quantity of prioritized objectives, whereas adjustment means an incremental transformation of existing objectives or rather their relative weighting. Generation describes the creation of absolute new objectives.
3. **Adapting the system's behavior**: An adaption of the system's behavior is required because of the modified system of objectives. This is done by adjusting

single parameters of the system or the whole structure. Finally, the loop of self-optimization is closed by this step.

The whole process is executed by the cooperation of all units of the system which perform the mentioned steps recurrent. Self-optimizing systems do not compulsory require cognitive capabilities up to a certain degree. Contrary, technical systems with cognitive capabilities are not necessarily self-optimizing. However, a technical system which fulfills the aforementioned definition of self-optimization completely has to possess cognitive capabilities in the narrow sense of the word especially regarding learning. This is highlighted by the fact that a self-optimizing system has to react "autonomously and flexible" to unforeseen changes [FGK+04].

3 State of the Art

3.1 Software Architectures for Cognitive Technical Systems

The integration of the above mentioned cognitive capabilities into a technical system is a promising approach to increase flexibility and adaptability of such a system. These cognitive technical systems have a specific architecture and are provided with artificial sensors and actuators to act in a physical world [ZW08]. In the field of autonomous robots, several architectures are proposed as a basis for these systems with cognitive behavior [Gat98, KST06]. The software architectures concentrate on the combination of a deliberative part for the actual planning process (planning layer) with a reactive part for the direct control (operation layer). Herein, the three-layer-architecture, shown in Fig. 1, with a cognitive, an associative and a reactive control layer is classified as a widespread approach [Rus03, Pae06].

The upper layer presents the **cognitive operator**. At this point, the system provides knowledge about itself and its environment to improve the own behavior. This is achieved by the use of various methods like planning and learning behavior, model-oriented optimization procedures or the application of knowledge-based systems. The **associative layer** in the middle supervises and controls the system. Here, the transferred modified behavior patterns from the cognitive layer are implemented by modifying the control in the reactive layer. A large part of auxiliary functions (like sequence control, monitoring and emergency procedures as well as adaption routines to improve the system behavior) are located in this layer. The **reactive layer** contains the control-oriented components of the information processing and manipulates the system behavior by connecting sensors and actuators to reach the required dynamics.

The architecture of cognitive technical systems often resort to modifications of architectural patterns like the presented layer model to implement the required system. However, the final architecture is adapted to the specific application to achieve the optimal performance of the system [HGH10]. Therefore, the architecture is ex-

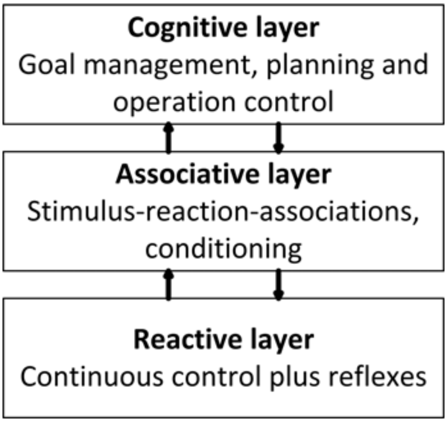

Fig. 1 Three-Layer-Architecture according to Paetzold [Pae06]

tended in many cases with a presentation layer on top of the other layers to guarantee a safe and clear human-machine interaction [HGH10] [SS10].

Advanced approaches of cognitive technical systems can be found in the field of autonomous vehicles and unmanned aerial vehicles (UAV) [Put04, OS10, TMD+07]. Within this field, especially the different architectures of the winning teams of the DARPA Grand Challenge, a competition for driverless vehicles funded by the Defense Advanced Research Projects Agency, the most prominent research organization of the United States Department of Defense, have to be referenced. Those regularly point out the current state of research [TMD+07]. Most of these architectures are based on the so called relaxed layered system, in which every layer can utilize the services of all layers located below. Hence, the flexibility and performance of the system rises with complete information in all layers [TMD+07].

Another CTS is developed within the collaborative research center 614. The Operateur-Controller-Modul (OCM) is designed to control a mechatronical system in the field of traffic engineering, in this case a drive and braking system as well as a spring and tilting system [FGK+04]. This architecture uses the layer model as well, while the cognitive capabilities are focused to enforce a self-optimization.

3.2 Cognitive Technical Systems in Production Engineering

For a few years cognitive technical systems are being explored in the field of production engineering but these systems are not yet ready to use in practice [BBB+11]. In addition to various research efforts like [LSB+11] and [MEJ+11] within the mentioned Cluster of Excellence at RWTH Aachen University and CRC 614, the Cluster of Excellence "Cognition in Technical Systems" (CoTeSys) at Technical University of Munich studies cognitive and self-optimizing (technical) systems with the vision of a cognitive factory [Clu].

Within this cluster, different approaches to implement cognitive capabilities in technical systems are being developed to improve primarily safe human-machine-interaction and -cooperation. The so called Cognitive Safety Controller (CSC) supervises the interaction between human operators and several robots inside of a production system [KDSS07]. Again, the architecture of this controller is based on the relaxed layered system. Instead, the objective of the project "Adaptive Cognitive Interaction in Production Environments" (ACIPE) consists in the implementation of an assistive system to autonomously plan a production process [ZW08]. Additional details are presented in Sect. 3.3.

Further general analyses about cognitive technical systems are related to [OS10] and, particularly in the field of production engineering, to [BBB+11] and [KDSS07].

3.3 Assembly Planning Systems

Assembly planning systems described in the literature do not relate cognitive technical systems. Therefore, the current state of technology of assembly planning systems is illustrated as part of assembly systems in general to be able to classify the explanations in the section below. Assembly planning systems are the main basis for the automated realization of assembly tasks. They plan the sequence of an assembly assumed that one or more production units or human workers are available. Every single action presents a work step which is executed by the robot or the worker.

At this point, the cognitive capability of planning from the field of artificial intelligence (AI) is of great interest. Numerous applicable approaches do exist for planning tasks in different applications. Hoffmann generated the so called Fast-Forward-Planer (FF) to derive action sequences for specified deterministic problems [Hof01], while other planners are able to deal with uncertainty [HB05]. However, all these planners are based on a symbolic logical representation. For the application of an assembly planning which is dependent on an appropriate representation of geometrical relations between states and the corresponding transformations this becomes very extensive even for simple tasks. Because of the generic characteristic, these planners collapse to calculate assembly sequences within an acceptable time.

Other planners were developed in particular for assembly planning. They directly operate with geometrical information and data to generate assembly sequences. A widespread approach is the "Archimedes" method, which uses the Assembly-by-Disassembly strategy in conjunction with an AND-/OR-graph to demount an assembly into its single parts [KWJ+96]. A further development of this is the planning strategy developed by Thomas [TMIW07], which uses solely the geometrical data of the assembly and the single parts and which reaches a higher degree of autonomy at that point. Despite this fact, these approaches are not able to deal with uncertainty, concerning the sequence of the delivered single parts.

The assembly planner mentioned in Sect. 3.2, is developed by Zaeh and Wiesbeck within the project ACIPE of the CoTeSys cluster [ZW08]. It computes the action sequence autonomously as far as possible, then presenting the result to the human operator. The planner is designed to support manual assembly, while the decision making for executing the sequence is still task of the worker and therefore not implemented in the system [SS10]. This planner works on a geometrical representation using a state graph. After generating the graph with the methods mentioned above, the current state of the system is matched to the graph after each manipulation and the optimal sequence is derived by a search algorithm [ZW08]. Related approaches are presented in [MCR10] and [BMDC10].

As described in this section, existing assembly planning systems nowadays possess only single cognitive capabilities like perception, action and especially planning, but they are neither cognitive at all nor self-optimizing. In the following, research activities are presented which try to close this gap.

4 The Project "Cognitive Planning and Control System for Production"

4.1 Objectives and Approach

The overall objective of the project "Cognitive Planning and Control System for Production" is to develop design methodologies for self-optimizing production with the use of cognitive control units that refer, for instance, to single machine controllers as well as to the organizational setup. Hence, a production system based on this reduces the work of planning in advance of an assembly and is capable of optimizing itself during the running process.

The basis of the system developed in this project is the software architecture shown in Fig. 2. The skeletal structure consists of the planning, coordination and reactive layer following the three-layer-architecture. This is supplemented by the presentation layer and a logging module to ensure that the operator is provided with situation-relevant information in order to be able to monitor the system as well as to perform a targeted system operation and to deliver a goal state. The knowledge module contains the knowledge base which comprises the domain knowledge that is necessary for the system with regard to the performance of the assembly tasks [HESJ10]. This architecture is connected with the technical layer, representing a robot cell. A detailed description of this architecture can be found in [HGH10].

An important cross section component of the system is the cognitive control unit (CCU), which plans and controls the assembly of a product solely described by its CAD data. The requirements for this planning component are to allow fast reaction times during assembly and a detailed generation of all possibilities to assemble the product from its single parts, which requires a large number of computations. Therefore, a hybrid approach has been designed which combines cognitive and therefore reactive capabilities with the functions of the assembly planning system as developed by Thomas [TMIW07] and extended by Zaeh [ZW08] (see Fig. 3). Another hy-

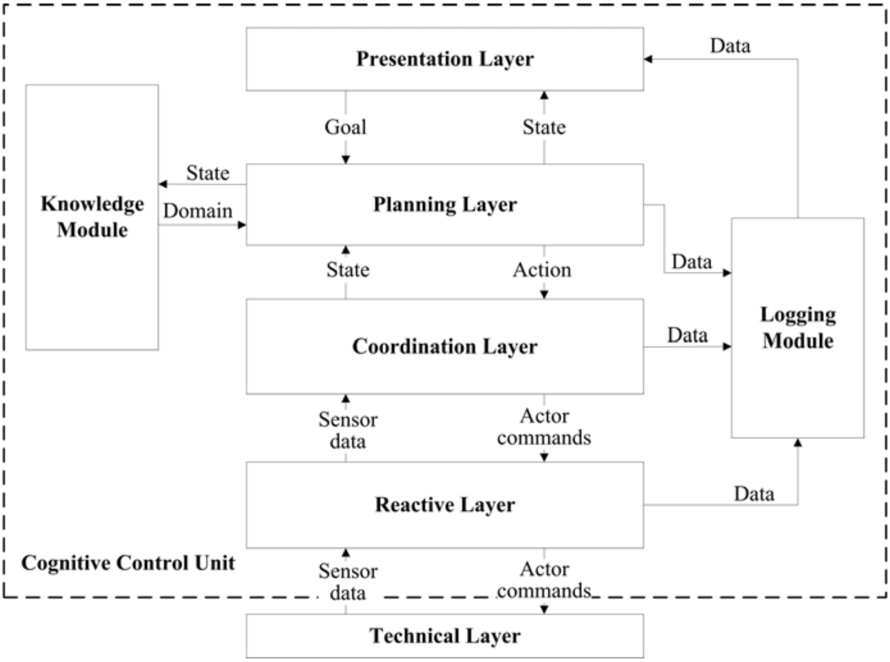

Fig. 2 Software architecture of the cognitive technical system

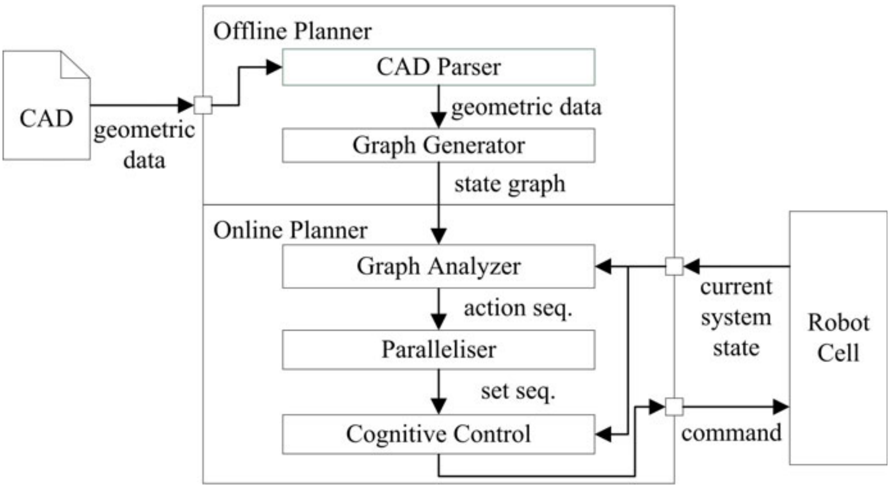

Fig. 3 Hybrid Planner of the CCU

brid planning approach for self-optimizing systems can be found in [Gau09], which distinguishes a discrete preplanning and a continuous online planning.

The offline planner of the CCU autonomously generates a state graph with all possible solutions to assemble a product prior to the actual assembly process and stores all information in the knowledge base. The online planner receives the current state of the system during the assembly and generates a set of optimal sequences which is analyzed by the subcomponent cognitive control. At this point, in contrast to Zaeh, the system itself reaches a decision and sends the command to the robot cell. The detailed procedure of the CCU is explained in [ETK+10]. By means of this approach, it is possible to react to unforeseen changes – in the constraints of the generated plan – concerning the environment, to increase the flexibility of assembly systems and to decrease the planning effort previously.

4.2 Cognitive Capabilities of the CCU

Based on the explanations from Sect. 4.1, the linkage between the components of the software architecture and the CCU on the one hand and the listed cognitive capabilities on the other hand is shown. In the following, the seven capabilities aforementioned and their methods or concepts of realization are illustrated:

- **Perception** is located in the lower layers of the architecture. While vision modules, which are part of the technical layer, collect the data from the environment, the reactive and coordination layer aggregate the information to a system state and transmit it to the planner [KHB09].
- **Reasoning** is a process which takes place in the knowledge module. Using the Web Ontology Language (OWL) as a means of representation in the knowledge base, structured storage of all information is allowed as well as an efficient access later on [HESJ10].
- **Remembering** is exactly this process of using the knowledge for planning or similar activities. This capability is provided by a knowledge compiler within the knowledge module [HESJ10].
- **Planning** is the main aspect of this system. It is performed by the planning layer more precisely by the CCU. This capability is implemented by means of graphical analysis in the graph generator and by classical search algorithms in this case the A* search algorithm in the graph analyzer [ETK+10].
- **Decision making** is the task of the cognitive control component. This component is based on Soar, a cognitive framework for decision finding, that aims on modeling the human decision process [LLR09]. An overview of Soar and other existing cognitive frameworks is given in [LLR09]. In addition to these general aspects, specific human behavior pattern concerning assembly processes can be implemented to support decision making [MSE+11].
- **Learning** is included in Soar as a learning mechanism called "chunking", which can store new rules in production memory [LLR09] . Concepts are being developed beyond that for example to lead back information of the assembly operation to the graph generation. This kind of 'reinforcement learning' allows improving the planning performance by learning from previous mistakes or failures.
- **Action** is, on the one hand, the direct realization of a command by a robot and its actuators. Therefore, the command is transformed into several control commands

by the coordination and reactive layer. On the other hand, the human operator can be asked to perform a work step. This is delivered by the human-machine interface in the presentation layer in an appropriate way [MSE+11].

To reach the performance of an automated assembly system concerning the execution speed all processes of a cognitive technical system described above have to be real-time capable. This is as well as the learning component subject of current research. As described before, the system contains several cognitive capabilities but still not being self-optimizing in terms of the named definition.

5 Conclusion and Outlook

By defining the terms *cognition* and *self-optimization* with respect to technical systems it was shown that both are not synonymous but cause each other in a certain way. A sophisticated self-optimizing system requires several cognitive capabilities in particular decision-making and learning. The implementation happens using a special category of architectures which usually base on the three-layer-model in combination with the relaxed layered system. Different cognitive technical systems from diverse scientific disciplines were presented with a focus on production engineering and assembly planning. The specifications of those architectures are tailored to the particular needs of the application.

Using the example of the project "Cognitive Planning and Control System for Production" the implementation of cognitive capabilities within one precise software architecture was presented. This autonomous assembly planning system is advanced but does not contain all required cognitive capabilities in a sufficient way. Especially the learning component has to be improved on the way to self-optimization.

The explanations have shown that the transfer of human cognitive capabilities to technical systems is yet not done sufficiently. On the one hand single components and methods to perform cognitive capabilities require further research as well as the integration of those components in a suitable architecture. As a result, the possibilities of an extend use of cognitive technical systems within production technology are immense. By means of a cooperation of several cognitive systems, the realization of self-optimizing production systems can be put forward. This approach has to be proved by industrial use cases while the current situation is fundamental research.

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Kognitive Planungs- und Lernmechanismen in selbstoptimierenden Montagesystemen

Christian Büscher, Sinem Kuz, Daniel Ewert, Daniel Schilberg, Sabina Jeschke

Zusammenfassung Der Einsatz automatisierter Produktionssysteme ist heute Stand der Technik in der Serien- und Massenfertigung. Die Automatisierung bietet zahlreiche Vorteile gegenüber manueller Fertigung, was sich in hoch spezialisierten, jedoch häufig unflexiblen Prozessen äußert. Sie erfordert eine detaillierte Programmierung der Steuerung, die beispielsweise bei Änderungen am zu fertigenden Bauteil hohe Kosten im Vorfeld mit sich bringt, die insbesondere bei kleinen Stückzahlen ins Gewicht fallen. Bislang bleiben darüber hinaus die ausgezeichneten kognitiven Fähigkeiten des Menschen unberücksichtigt. Ziel ist es daher, die Vorteile von automatisierter und manueller Fertigung zu vereinen. Dies kann durch die Integration kognitiver Fähigkeiten und Selbstoptimierungskomponenten in automatisierte Produktions-systeme erreicht werden, womit die Flexibilität der Systeme bei gleichzeitig steigender Planungseffizienz erhöht wird. Daraus resultiert auch ein effizienterer Einsatz in der Kleinserienfertigung bzw. bei variantenreicher Produktion. Am Beispiel eines kognitiven technischen Systems zur automatisierten Montageplanung, das als Interaktionssystem den Menschen einbindet und somit nicht vollkommen autonom handelt, wird eine konkrete Umsetzung dargelegt, die die beschriebene Integration aufzeigt. Das System verfügt über zahlreiche kognitive Fähigkeiten, die die Effizienz des Planungsprozesses erheblich steigern. Die Umsetzung der hierfür entscheidenden kognitiven Fähigkeiten des Planens und Lernens wird im Detail beleuchtet.

Schlüsselwörter: Kognitive Lernmechanismen, Hybrider Planungsansatz, Selbstoptimierung, Montageplanungssystem

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1 Einleitung

Fertigungs- und Montagesysteme müssen aufgrund von immer kürzer werdenden Produktlebenszyklen und sich ständig ändernden Kundenanforderungen flexibel sein, um schnell auf Änderungen der Produkte und ihrer Varianten zu reagieren. Hochautomatisierte Fertigungssysteme sind jedoch weder effizient genug für eine Kleinserienproduktion noch flexibel genug, um Produkte mit einer Vielzahl von Varianten zu fertigen [BBB+11]. Um die Flexibilität zu erhöhen, wird zunehmend angestrebt, in zukünftige Fertigungssysteme die außergewöhnliche Problemlösungsfähigkeit, Kreativität und sensomotorische Begabung des Menschen stärker zu integrieren [SRL02]. Basierend auf künstlichen kognitiven Fähigkeiten sollten technische Systeme nicht nur in der Lage sein, eine (halb-) automatische Fertigungsplanung vorzunehmen, auf veränderte Umgebungsbedingungen zu reagieren und aus Erfahrungen zu lernen, sondern auch zielorientiertes menschliches Verhalten abzubilden, um somit die Flexibilität des Systems drastisch zu steigern. Damit können effektive, effiziente und schließlich selbstoptimierende, kognitive Systeme erzeugt werden [ZW08]. Mit dem Ziel des Transfers der menschlichen kognitiven Fähigkeiten auf technische Systeme ist die Thematik der Kognition in verschiedenen wissenschaftlichen Disziplinen von großer Bedeutung. Im Bereich der Produktionstechnik und dort insbesondere in der Montageplanung existieren vor diesem Hintergrund heute nur wenige Ansätze (Abschn. 3). Kognitive Systeme können hier jedoch einen enormen technologischen und wirtschaftlichen Fortschritt mittels Selbstoptimierung und der damit verbundenen autonomen Anpassung des Systemverhaltens an vorgegebene Zielzustände herbeiführen.

In diesem Beitrag werden zunächst die in diesem Kontext entscheidenden Definitionen der Begriffe Kognition und Selbstoptimierung als Ausgangsbasis aufgeführt. Der Fokus liegt im weiteren Verlauf auf kognitiven technischen Systemen im Anwendungsfeld der automatisierten Montageplanung. Nach einem kurzen Abriss des Stands der Technik wird eine konkrete Umsetzung eines derartigen Systems präsentiert. Innerhalb des Exzellenzclusters „Integrative Produktionstechnik für Hochlohnländer" der RWTH Aachen University werden Grundlagen für nachhaltige produktionswissenschaftliche Strategien und Theorien sowie notwendige technologische Ansätze erforscht. Im Forschungsfeld „Selbst-optimierende Produktionssysteme" wird innerhalb des Teilprojekts „Kognitive Steuerungs-systeme für die Produktion" ein kognitives Montagesystem entwickelt und implementiert. Neben einer kurzen Beschreibung der Forschungstätigkeiten in Abschn. 4 wird insbesondere auf die Umsetzung der kognitiven Fähigkeiten Planung und Entscheidungs-findung (Abschn. 5) und Lernen (Abschn. 6) mit dem Ziel der Selbstoptimierung und damit der Flexibilitätssteigerung von automatisierten Systemen eingegangen. Der Betrag schließt mit einer Zusammenfassung sowie einem Ausblick in Abschn. 7.

2 Begrifflichkeiten

Der Begriff Kognition wird in der Literatur nicht einheitlich und überwiegend aus einer menschzentrierten Perspektive definiert. Innerhalb der Psychologie existieren zahlreiche Definitionen. Eine gängige ist die von Matlin, die Kognition in diesem Kontext als Aneignung, Speicherung, Verarbeitung und Nutzung von Wissen darlegt, wobei Wissen als Aggregation von Informationen bezogen auf den Menschen zu verstehen ist [Mat08]. Strohner erweitert den Begriff auf technische Systeme indem er Kognition als jede Art von Informationsverarbeitung des zentralen Nervensystems eines Menschen oder eines vergleichbaren künstlichen Systems definiert [Str95]. In Bezug auf technische Systeme sind (1) Wahrnehmung, (2) Schlussfolgerung, (3) Erinnerung, (4) Planung, (5) Entscheidungsfindung (6) Lernen und (7) Handlung diejenigen kognitiven Eigenschaften, die für diese Prozesse notwendig sind [BBB+11], [Str95].

Die **Wahrnehmung** bezeichnet dabei den Prozess der Aufnahme von sensorischen Daten und deren Verarbeitung und Aggregation zu Informationen. Dies wird durch eine kontinuierliche Beobachtung des Systems selbst und dessen Umwelt erreicht. **Schlussfolgerung** beschreibt den Vorgang des induktiven und deduktiven Wissensgewinns auf Basis von bereits vorhandenem Wissen und der einhergehenden Annahme über die Umwelt [BBB+11]. **Erinnerung** ist die Fähigkeit, die Ergebnisse von kognitiven Prozessen zu verschlüsseln und zu speichern, und dieses zu einem späteren Zeitpunkt wieder abzurufen. Die **Planung** bezieht sich in der Regel auf kognitive Vorgänge im menschlichen bzw. künstlichen Gehirn zur Erstellung eines Plans, der dann als eine Menge von Aktionen abgebildet wird. Somit ist die Planung die Grundlage für die **Entscheidungsfindung**, wobei eine Entscheidung im Abgleich mit einem Zielzustand herbeigeführt wird und somit ein entsprechendes Verhalten hervorruft [Str95]. Eine wichtige kognitive Fähigkeit ist das **Lernen**. Aus den Erfahrungen und den sensorischen Informationen werden neue Verhaltensweisen und Wissen geschaffen. Dieser Wissensgewinn unterscheidet sich in der Form von Schlussfolgern, dass explizit neues Wissen generiert wird. Schließlich beinhaltet die **Handlung** die Umsetzung der zuvor genannten Fähigkeiten über die Manipulation der Umwelt.

Kognition ist somit auf dem Weg zur Selbstoptimierung von Produktionssystemen eine wesentliche Bedingung. Dies wird durch die Definition des Begriffs Selbstoptimierung innerhalb des Sonderforschungsbereichs 614 „Selbstoptimierende Systeme des Maschinenbaus“ (SFB 614) der Universität Paderborn untermauert [Son]:

„Unter Selbstoptimierung eines technischen Systems wird die endogene Änderung der Ziele des Systems auf veränderte Einflüsse und die daraus resultierende zielkonforme autonome Anpassung der Parameter und ggf. der Struktur und somit des Verhaltens dieses Systems verstanden. Damit geht Selbstoptimierung über die bekannten Regel- und Adaptions-strategien wesentlich hinaus; Selbstoptimierung ermöglicht handlungsfähige Systeme mit inhärenter „Intelligenz“, die in der Lage sind, selbstständig und flexibel auf veränderte Betriebsbedingungen zu reagieren.“

3 Stand der Technik

Montage(planungs)systeme können heutzutage noch nicht als kognitive technische Systeme bezeichnet werden. Sie bilden jedoch die Grundlage für eine automatisierte Planung und Steuerung von Montageaufgaben, zu deren Umsetzung ein oder mehrere Roboter bzw. Produktionseinheiten sowie der Mensch zur Verfügung stehen. An dieser Stelle spielen klassische Planungsalgorithmen und solche aus dem Bereich der künstlichen Intelligenz eine wesentliche Rolle. Es existieren zahlreiche geeignete Ansätze für verschiedene Planungsaufgaben in unterschiedlichen Anwendungsgebieten. Im Bereich der Montage-planung ist das „Archimedes“ System ein grundlegender Ansatz [KWJ+96]. Mit Hilfe der sogenannten „Assembly-by-Disassembly“ Strategie und eines Montagegraphen wird das Endprodukt in seine Einzelteile zerlegt und somit die Montageplanung realisiert. Eine Weiterentwicklung dieses Ansatzes ist die Planungsstrategie von Thomas, die für die Berechnung lediglich die geometrischen Daten der Einzelteile und des Endprodukts benötigt und somit an dieser Stelle einen höheren Grad an Autonomie erzeugt [Ulr08]. Jedoch sind diese Ansätze nicht adaptiv und somit nicht in der Lage, mit Unsicherheit in Bezug auf die Verfügbarkeit der Einzelteile umzugehen.

Seit einigen Jahren werden kognitive technische Systeme im Bereich der Produktionstechnik erforscht, wobei die praktische Anwendung bislang noch nicht erreicht wurde [BBB+11]. Neben dem erwähnten Exzellenzcluster an der RWTH Aachen University und dem SFB 614 beschäftigt sich insbesondere der Exzellenzcluster „Cognition in Technical Systems“ (CoTeSys) der TU München mit kognitiven und selbstoptimierenden (technischen) Systemen mit dem Ziel der Kognitiven Fabrik. Innerhalb dieser Cluster werden verschiedene Ansätze für die Umsetzung von kognitiven Fähigkeiten in technischen Systemen erforscht. Das Ziel des Teilprojekts „Adaptive Cognitive Interaction in Production Environments“ (ACIPE) des CoTeSys-Clusters ist es dabei, ein unterstützendes System zur Montageplanung zu implementieren [ZW08]. Dieser Ansatz von Zaeh und Wiesbeck berechnet die Montagesequenz so weit wie möglich autonom und übergibt diese dem Bediener zur Ausführung. Dabei arbeitet der Planungsalgorithmus basierend auf den geometrischen Daten mit einem Zustandsgraphen (Abb. 3) [ZW08]. Nachdem der Graph erzeugt wurde, wird der aktuelle Systemzustand ausgelesen, mit dem Graphen verglichen und daraufhin die optimale Sequenz mit klassischen Suchalgorithmen bestimmt. Die Entscheidungsfindung liegt bei diesem Ansatz jedoch beim Bediener und ist nicht im System implementiert.

Wie zuvor beschrieben, sind existierende Montageplanungssysteme heutzutage nicht in der Lage, kognitiv und selbstoptimierend zu arbeiten, da dem System insbesondere Fähigkeiten wie Entscheidungsfindung und Lernen fehlen. Im weiteren Verlauf wird ein Ansatz aufgezeigt, dessen Ziel es ist, genau diese Lücke zu schließen.

4 Anwendungsfall

Innerhalb des Teilprojekts „Kognitive Steuerungssysteme für die Produktion“ des Exzellenzclusters „Integrative Produktionstechnik für Hochlohnländer“ der RWTH Aachen University wird ein kognitives Montageplanungssystem entwickelt und implementiert. Das Ziel ist die Entwicklung von Entwurfsmethodiken für die selbstoptimierende Produktion unter Verwendung von kognitiven Kontrolleinheiten. Ein derartiges Produktionssystem reduziert zum einen den Planungsaufwand im Vorfeld einer Montage und spart somit enorm viel Zeit und Kosten. Zum anderen ist es in der Lage, sich selbst während des Montageprozesses zu optimieren, wodurch die Flexibilität des Systems gesteigert wird.

Die Grundlage für dieses System bildet eine mehrschichtige Softwarearchitektur, die zum einen über eine technische Schnittstelle verfügt, an der eine Roboterzelle oder eine Simulationssoftware angeschlossen werden kann. Zum anderen existiert eine Mensch-Maschine-Schnittstelle. Darüber kann das System Anfragen bzw. Anweisungen an den Bediener kommunizieren und diesem den Systemzustand der Roboterzelle transparent anzeigen. Zudem verfügt das System über eine Wissensbasis, die Produktionsregeln sowie Informationen über die Roboterzelle und die zu fertigenden Produkte beinhaltet. Die gesamte Architektur ist so ausgelegt, dass sie die in Abschn. 2 beschriebenen kognitiven Fähigkeiten verarbeiten kann. Eine detaillierte Beschreibung dieses Systems ist in [HGH10] zu finden. Ein weiterer wichtiger Bestandteil ist die kognitive Planungs- und Steuerungseinheit (CCU; engl. für cognitive control unit), deren Ziel die automatisierte Planung und Durchführung einer Montageaufgabe ist. Dabei erhält die CCU die geometrischen Daten des zu montierenden Produkts in Form einer CAD-Datei und plant und steuert den gesamten Montageprozess weitestgehend autonom [ETK+10]. Zu diesem Zweck wurde aufbauend auf den in Abschn. 3 vorgestellten Montageplanungssystemen ein hybrider Planungsansatz entwickelt und implementiert. Eine genaue Erläuterung der Prozesse der CCU erfolgt in Abschn. 5.

Das vorgestellte kognitive technische System wird mit dem in Abb. 1 dargestellten Szenario evaluiert. Die angesteuerte Montagezelle besteht aus zwei Robotern und einem umliegenden Fördersystem. Während der eine Roboter lediglich die Einzelteile des zu montierenden Produkts in beliebiger Reihenfolge in den Montagebereich bringt, werden der eigentliche Montageroboter (rechter Roboter in linker Abbildung) und das Fördersystem durch die CCU gesteuert.

Zur virtuellen Ausführung dieser Planung kann zudem das Simulationsprogramm KUKASim Pro der KUKA Roboter GmbH an die Architektur angebunden werden. Dazu wurde zunächst eine realitätsgetreue virtuelle Darstellung der realen Anlage erstellt (rechter Teil von Abb. 1). Die Schnittstelle zwischen CCU und KUKASim Pro wurde in der Form implementiert, dass die CCU alle Funktionalitäten wie Bewegungsabläufe in der Simulation entsprechend der realen Roboterzelle ansprechen und verwenden kann. Nach der Ausführung einer Aktion in der Simulation können darüber hinaus verschiedene nützliche Daten wie die Ausführungsdauer oder Fehler bei einer Montageaktion ausgelesen werden, wodurch neue Erkenntnisse gewonnen und in späteren Montageaufgaben eingesetzt werden können.

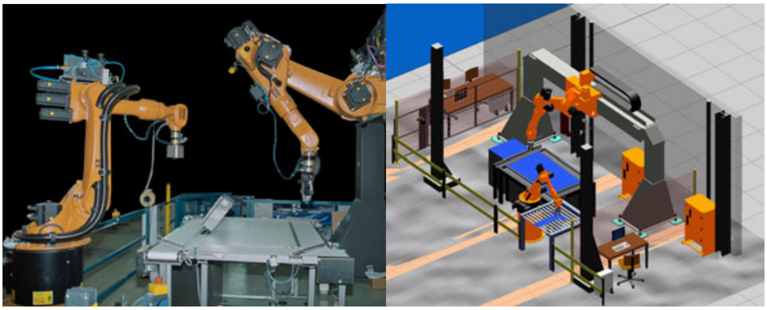

Abb. 1 Layout der Roboterzelle

5 Hybrider Planungsansatz

Die Aufgabe der kognitive Planungs- und Steuerungseinheit (CCU) besteht in der Planung und Steuerung der Montage eines Produkts, das ausschließlich über seine CAD-Daten beschrieben wird. Dabei plant und führt das System die Montage selbstständig aus, nachdem weitere Informationen wie das vorgegebene Zielsystem durch den Bediener eingegeben worden sind und kooperiert während des Prozesses mit ihm. Während ein Großteil der Arbeitsschritte von der Roboterzelle ausgeführt wird, können einzelne Montageschritte oder korrigierende Eingriffe heute nur vom Menschen vollzogen werden.

Aufgrund einer zufälligen Bauteilzuführung und der damit verbundenen Unsicherheit kann der nächste Systemzustand der Roboterzelle nicht vorhergesagt werden. Die CCU ist somit einem nicht-deterministischen Planungsproblem konfrontiert, das eine ständige Neuplanung während der Montage erfordert [ETK+10]. Um schnelle Reaktionszeiten während der Montage zu gewährleisten, verfolgt der vorgestellte Ansatz eine hybride Planung, bestehend aus einem Offline und einem Online Planer. Die eigentliche Planungsaufgabe, die mehrere Stunden in Anspruch nehmen kann, wird im Offline Planer mit der Generierung eines Montagegraphen vor der Montage gelöst. Während der Montage wird dieser Graph im Online Planer fortwährend aktualisiert, darauf aufbauend die optimale Montagesequenz ermittelt und schließlich der nächste Befehl an die Roboterzelle bzw. die Simulation gesendet. Das Vorgehen und der Aufbau der CCU sind in Abb. 2 dargestellt.

Ausgehend von der geometrischen Beschreibung des Endprodukts und der beinhalteten Einzelteile wird in der Komponente Graph Generator des Offline Planers der gesamte Lösungsraum des Montageplanungsproblems aufgespannt. Basierend auf diesen Informationen wird die „Assembly-by-Disassembly" Strategie angewendet um einen Zustandsgraphen zu erzeugen, der effizient vom Online Planer ausgelesen werden kann. Der Hauptansatz dieser Strategien besteht darin, dass eine Baugruppe in zwei Einzelteile oder Unterbaugruppen zerlegt wird, bis ausschließlich Einzelteile übrig sind [KWJ+96]. Der fertige Zustandsgraph (Abb. 3) beinhaltet alle möglichen Systemzustände, die während der Montage auftreten können, und die notwendigen Informationen für die Transformationen zwischen diesen. Das umfasst

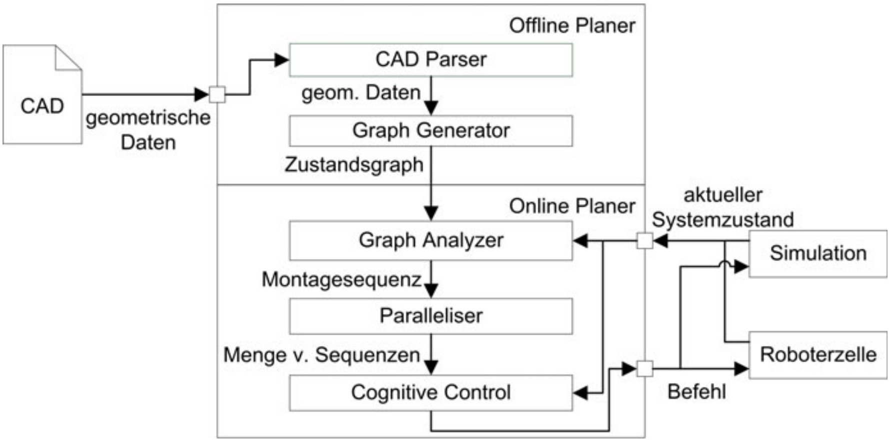

Abb. 2 Aufbau der Kognitiven Planungs- und Steuerungseinheit (CCU)

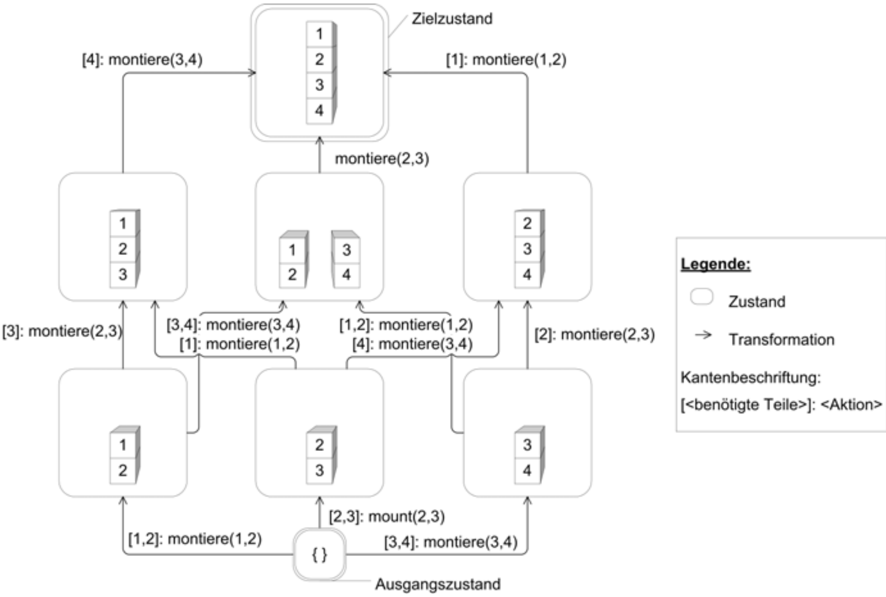

Abb. 3 Zustandsgraph am Beispiel eines 4-blöckigen Turms

auch die Kosten der entsprechenden Montageaktion wie z. B. Dauer, Ausführungsorgan oder Werkzeugwechsel, die als Kantenkosten repräsentiert werden.

Der Online Planer ist für die Steuerung während der Montage zuständig. Dafür nutzt der Planer den zuvor generierten Zustandsgraphen und reichert ihn mit aktuellen Zustandsdaten des Systems oder der Simulation an. Der Graph Analyzer verortet zunächst den aktuellen Systemzustand im Graphen. Falls der Ist-Zustand mit dem Zielzustand des Endprodukts übereinstimmt, ist die Montage beendet. In allen anderen Fällen erfolgt zunächst eine Update-Phase, bei der die oben angesprochenen Kantenkosten auf Basis des Systemzustands angepasst werden. Insbesondere die Nichtverfügbarkeit von benötigten Einzelteilen verursacht dabei „Strafkosten", sodass die entsprechenden Montageaktionen in der folgenden Berechnung gemieden werden [ETK+10]. Darin wird die optimale Montagesequenz vom aktuellen Ist- zum Zielzustand berechnet. Es wird der A*-Algorithmus verwendet, der denjenigen Pfad zum Zielknoten mit der geringsten Summe an Kantenkosten identifiziert. Diese Montagesequenz wird an die Komponente Paralleliser übergeben.

Die Aufgabe des Paralleliser ist die Überprüfung der optimalen Montagesequenz auf die Möglichkeit der parallelen Ausführbarkeit zweier oder mehrerer Aktionen. Sind zwei Montageaktionen unabhängig voneinander ausführbar, werden diese zu einer Menge von Aktionen zusammengeführt. Diese Permutation wird für die gesamte übergebene Montagesequenz auf Basis des Graphen wiederholt, so dass schließlich eine Menge von Sequenzen an die Komponente Cognitive Control (kognitive Steuerung) übergeben wird. Dies hat den Vorteil, dass die Montage beschleunigt wird, da z. B. eine gleichzeitige Manipulation durch den Bediener und die Roboterzelle möglich ist. Zudem werden die Freiheiten der Entscheidungsfindung des Systems deutlich ausgeweitet und das gesamte System somit flexibler.

Die eigentliche Montage wird von der kognitiven Steuerung geleitet. Diese basiert auf Soar, einem kognitivem Framework zur Entscheidungsfindung, das den menschlichen Entscheidungsprozess abbildet [LLR09]. Somit wird trotz der beabsichtigten Eigenständigkeit des Systems eine hohe Maschinentransparenz erzielt. Diese Komponente ist verantwortlich für die Aktivierung einer konkreten Montageaktion basierend auf der Menge von Sequenzen des Paralleliser und des aktuellen Systemzustands aus der Roboterzelle bzw. der Simulation. Die kognitive Steuerung wählt dazu auf Basis des übergebenen Zielsystems aus der Menge von Sequenzen die optimale Aktion aus und entscheidet somit selbst über die zu realisierende Montagereihenfolge. Diese wird in Form einzelner Roboterbefehle bzw. als Anweisungen an den Bediener extrahiert. Im Fall von unvorhersehbaren Änderungen der Umwelt, z. B. durch die Zuführung neuer Bauteile, kann die Komponente eine Neuplanung durch den Graph Analyzer veranlassen oder eine Anfrage an den Bediener stellen. Somit umfasst die CCU, im Gegensatz zu dem von Zaeh und Wiesbeck entwickelten Ansatz, die kognitive Fähigkeit der zielorientierten Entscheidungsfindung.

6 Lernmechanismen der CCU

Neben den zuvor präsentierten kognitiven Fähigkeiten der Planung und Entscheidungsfindung ist das Lernen eine entscheidende Fähigkeit zur Erzeugung von kognitiven und selbstoptimierenden Aktivitäten. Die Ausgangsdaten für das Lernen stammen aus den übrigen kognitiven Prozessen des Systems. In diesem Anwendungsfall werden zwei Arten von Lernen abgebildet. Zum einen verfügt Soar über das sogenannte „Chunking" und zum anderen kann die CCU bei der realen Aus-

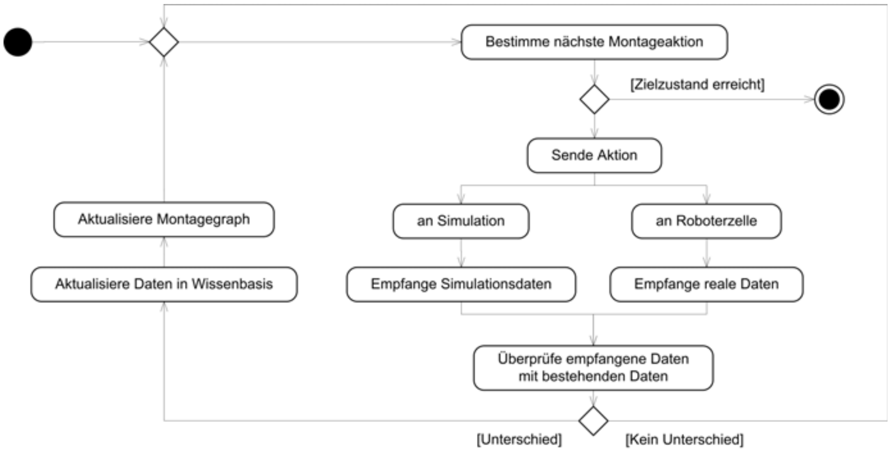

Abb. 4 Aktivitätsdiagramm des Lernmechanismus der CCU

führung bzw. der Simulation von Montageaktionen z. B. aus Fehlern für zukünftige Montageaufgaben lernen.

Soar beinhaltet zahlreiche Lernmechanismen für verschiedene Arten von Wissen. Von entscheidender Bedeutung ist hier das Chunking. Dieses findet statt, wenn Ergebnisse in einem Unterziel erreicht werden. In diesem Fall lernt Soar einen neuen 'Chunk', der die Prozesse zur Ergebniserzeugung im übergeordneten Ziel zusammenführt und als neue Produktionsregel in der Wissensbasis ablegt [LLR09]. Nach der Generierung eines neu erlernten Chunk wird dieser auf alle vergleichbaren Situationen angewendet und beschleunigt somit die Planung. Durch diese Verallgemeinerung von spezifischen Situationen ist Soar und damit die CCU in der Lage, zukünftige Montageaufgaben effizienter zu steuern.

Neben diesem kleinen Regelkreis besteht die Möglichkeit, durch einen 'intelligenten' Datenfluss innerhalb der CCU einen weiteren Lernmechanismus zu realisieren. Die kognitive Steuerung leitet den Kommunikationsfluss zwischen CCU und Roboterzelle bzw. Simulation. Sie übermittelt den nächsten Montagebefehl und erhält im Gegenzug Informationen über den getätigten Arbeitsschritt. Diese Informationen können in der Wissensbasis abgelegt und ausgewertet werden. Somit ist das System in der Lage, eine Verbesserung des Planungsverhaltens durch Lernen aus realisierten Montageaktionen zu erzielen. Dieser Lernmechanismus ist eine Art „Reinforcement Learning" [LLR09]. Reinforcement Learning beschreibt eine Reihe von Methoden des Maschinellen Lernens, bei denen ein Agent den Nutzen von Aktionssequenzen bestimmt. Das bedeutet im Detail, dass ausgeschüttete Belohnungen über vorangegangene Aktionen so zu implementieren sind, dass dem Agenten der Nutzen jeder Aktion bekannt ist und er diesen ausschöpfen kann [LLR09]. Die Umsetzung dieses Mechanismus in der CCU ist in Abb. 4 dargestellt.

Der Prozess der Montageplanung und Entscheidungsfindung wurde bereits in Abschn. 5 dargelegt. An dessen Ende wird die als nächstes auszuführende Montageaktion von der kognitiven Steuerung an die Roboterzelle bzw. die Simulation gesendet. Im Gegenzug empfängt der Online Planer nach Ausführung der Aktion den aktuellen Systemzustand inklusive relevanter Informationen über die Transaktion. Das beinhaltet zum einen reine Verlaufsdaten wie die Zeitdauer oder den Ressourceneinsatz. Diese Daten werden mit den im Zustandsgraph abgespeicherten Kantenkosten verglichen. Bei einer Differenz werden die entsprechenden Daten in der Wissensbasis aktualisiert und die Kantenkosten gemäß der ermittelten Bewertung im Graphen angepasst. Des Weiteren werden Informationen über den Erfolg der Transaktion, also über Fehler bei der Montage oder anderweitige Störungen, übertragen. Auch diese Daten werden in die Wissensbasis und den Graphen übernommen. Fehlerfreie Transaktionen erhalten geringe Kosten, mit Fehlern behaftete Transformationen werden hingegen mit „Strafkosten" behaftet, um die angesprochene Belohnung zu implementieren. Somit werden diese fehlerhaften Montageaktionen bei einer folgenden Berechnung der optimalen Sequenz oder bei zukünftigen Montageaufgaben gemieden.

Dieser Lernmechanismus entfaltet seine ganze Leistung, wenn nach der Generierung des Graphen durch den Offline Planer die Montage zunächst simuliert wird. Hierbei werden bereits die Kantenkosten mit möglichst realen Werten hinterlegt, um im folgenden Realbetrieb mit Hilfe dieser Erfahrungswerte ein Planungs- und Entscheidungsverhalten der CCU nahe dem optimalen Betriebspunkt hervorzurufen. Aber auch im Realbetrieb kann die CCU auf Störungen, Fehlverhalten und Prozessschwankungen reagieren. Somit erzeugt dieser Lernmechanismus ein selbstoptimierendes Verhalten.

7 Zusammenfassung und Ausblick

In diesem Beitrag wurde ein automatisiertes Montageplanungssystem vorgestellt. Ausgehend von einer Beschreibung von kognitiven Fähigkeiten als Grundvoraussetzung für die Selbstoptimierung technischer Systeme, wurde die Entwicklung und Implementierung einer kognitiven Planungs- und Steuerungseinheit aufgezeigt, die diese Fähigkeiten besitzt. Von entscheidender Bedeutung sind an dieser Stelle die kognitiven Fähigkeiten der Planung und Entscheidungsfindung sowie des Lernens. Unter Verwendung eines hybriden Planungsansatzes, der Integration von Soar als Entscheidungskomponente und der Implementierung eines Lernmechanismus als Art Reinforcement Learning befindet sich dieses Montageplanungssystem auf dem Weg zur Selbstoptimierung.

Insgesamt bewegen sich die aktuellen Bemühungen zur Implementierung von kognitiven technischen Systemen in der Montageplanung im Bereich der Grundlagenforschung. Der Transfer von kognitiven Fähigkeiten hin zu technischen Systemen ist noch nicht ausreichend vollzogen. Einzelne Komponenten und Methoden zur Umsetzung müssen ebenso weiter erforscht werden, wie die Integration dieser in ein entsprechendes Gesamtsystem. Auf diese Weise wird die Verwirklichung von selbstoptimierenden Produktionssystemen, die hochflexibel und kosteneffizient arbeiten, weiter voran gebracht. Dieser Ansatz muss jedoch durch die industrielle Anwendung nachgewiesen werden.

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An Agent-Based Concept for Planning and Control of the Production of Carbon Fibre Reinforced Plastics Aircraft Structures with Mobile Production Units

Franz Dietrich, Christian Löchte, Sabina Jeschke, Annika Raatz

Abstract This article is concerned with the control of the production of aircraft primary structures made of carbon fibre reinforced plastics. To increase the parallelization of the production, a scenario that implies new design paradigms is discussed. In order to realize this parallelization, mobile production entities work concurrently at the same primary structure of the fuselage. The present article proposes a software architecture for the control of such a production system. It is proposed that components are organized hierarchically. In enhancement to previous proposals, two perspectives of hierarchy are used here: grouping by functionality and grouping by timing context. The core of the architecture is a market-based multi-agent system, where the agents may operate in multiple timing contexts. Such a design yields advantages in terms of fast integration of new functionalities and scale-up of the production system. In brief, this article introduces a top-level control architecture for parallelized production of large reliable CFRP structures in a scalable production system.

Key words: Assembly Automation, Multi-Agent System, Control Architecture, Mobile Robots

1 Introduction

Recently developed commercial aircrafts confirm the hypothesis that carbon fibre reinforced plastics (CFRP) increase in aircrafts' primary structure. Airbus, for ex-

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ample, states that “over 70 per cent of the A350 XWBs weight-efficient airframe is made from advanced materials, combining 53 per cent of composite structures with titanium and advanced aluminum alloys.“ [Air12]. Among the challenges that come with this shift in paradigm there is the production technology of the primary structure, which conducts the main loads inside the fuselage [Fär10]. Such structures feature large surfaces on which carbon fibres have to be placed in multiple layers. Their automated production commonly involves fibre placement machines, for example tape laying machines. These machines, a bottleneck in the production chain, continuously become faster (currently 60 m/min [M.T12]) to shorten cycle times, but one may expect that technological limits of the laying speed are not far away. This hypothesis may lead to the proposal that parallelization of this production process is a viable approach to break current limitations.

Parallelization can be implemented only when the product is designed suitably. This means that it must be possible to execute production tasks concurrently. The authors share the opinion that even more advances are to be expected if both, the design of CFRP primary structures and the production technologies evolve in conjunction.

This topic is treated within a cooperation of German Aerospace Center (DLR), RWTH Aachen and TU Braunschweig. Within this cooperation, the present article evolved.

The article addresses top-level issues related to algorithms and software architecture for planning and control. This is driven by the insight that such infrastructure is required to merge the individual technologies that contribute to this scenario. The following section introduces the proposal, setting emphasis on the challenges for planning and control of the production. Subsequently, a system architecture is proposed, providing common blueprints for the implementations of particular aspects. In order to form a comprehensive image, it is shown from multiple perspectives that are relevant for the level of abstraction of interest to the present article. In summary, the authors intend to introduce a top-level control architecture for parallelized production of large reliable CFRP structures in a scalable production system.

2 A Scenario for the Production of CFRP Primary Structures

2.1 Overview

Figure 1 shows a simplified sketch of the scenario under cosideration. The scenario implies that the primary structure of the fuselage is based on a lattice frame. This frame is, similar to the grid structures presented in [VBR01, VR06], designed to take up all main loads that occur during the operation of the aircraft.In contrast to the cited ressources, it is intended in the present scenario to generate the frame in multiple layers of endless CFRP tapes. This generative process is suitable for parallelized production because there may be numerous production entities involved, for example tape laying robots, that work together in parallel. The primary structure

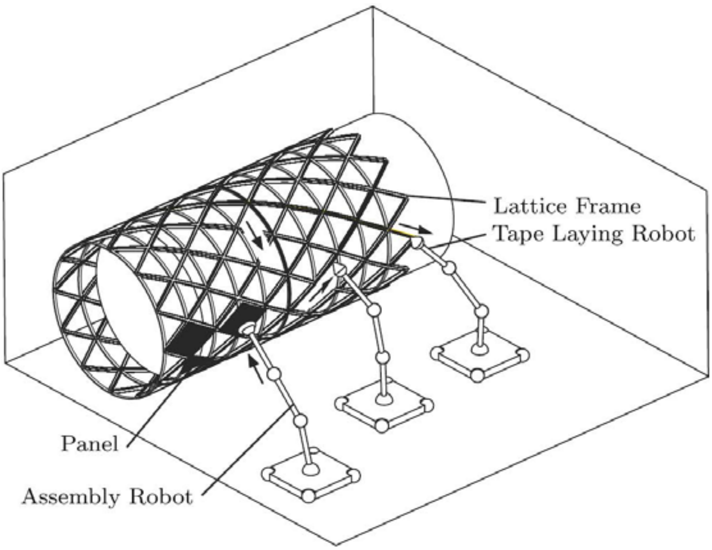

Fig. 1 Scenario for production of primary structure made of CFRP fibre tapes and panels

is considered to be too large to be moved frequently. Instead, it is prefered to move the production entities around an immoveable "construction site". This commitment results in the need for coordinated action of these entities because their workspaces intersect, for example when tapes cross each other.

When the production process of a particular frame has progressed up to a certain degree, other production entitites start to cover it with panels. These panels, also made of CFRP but pre-produced in an external process, conduct forces locally only to forward them to the lattice structure. In comparison to the size of the fuselage, their size is rather small. This means for the production system that there are many panels that need to be mounted to the lattice frame.

In addition to the panels, larger structures have to be mounted on the primary structure in one piece. These structures are of considerable variety, for example stringers, floor elements or even the wing box. Their differences in size and shape challenge the design of generic gripping and fixture devices as well as their respective assembly strategies.

2.2 Challenges for Control Algorithms and Software Architecture

The most importance challenge arises from the large size of the product (the primary structure) and its complexity that requires many atomic production steps. These steps, which may be as different as tape laying, mounting of small panels, and mounting of larger structures, cannot be separated into multiple locations. This density in conjunction with the goal to maximize parallelization requires that tasks of very different character are executed concurrently next to each other. Moreover, it means that a large number of production entities have to be coordinated and controlled. This requires an infrastructure to implement efficient planning and control.

The challenge of control becomes even more complex, if the production entities are mobile. This is a noteable enhancement in comparison to related research, which reports mostly about scenarios where only the flow of workpieces is variable. In the scenario investigated here, also the production entitites move within the environment of the emerging product. This adds favorable degrees of freedom, but increases also the likelihood of concurrency and collision to be handled by the control system.

The following text elaborates selected aspects of the overall challenge that are of relevance for the structure and the execution scheme of the control architecture.

2.2.1 Concurrency and Coordination

Advantages can be expected if the planning algorithm and the control system support mechanisms of concurrent execution of production tasks. This results from the aim to parallelize production tasks so that multiple units can work concurrently at the same workpiece.

2.2.2 Planning

Initially, the assembly planning system is in the fortunate situation that a dependency graph can be obtained. This graph contains the possible assembly sequences that result in the desired product configuration. However, in order to succeed, a planning system should also be able to support manual planning. For example, simple planning procedures within a smaller scope could be executed automatically, and for more complicated tasks, the planning system might propose viable solutions to be confirmed by a human planer.

When planning, the multi-objective character of the missions must be taken into account. Objectives, such as time-to-complete, slim in-house-logistics, efficiency in general, energy consumption and expected error-rate, yield antagonistic optimization targets, from which a compromise has to be chosen. Offline planning gives a plan to start with, but various incidents will require online replanning or rescheduling of tasks – at least within a certain planning horizon.

2.2.3 Control Loops for Tasks of Ad-Hoc Teams

It is intended that there are tasks which require a team of production units, for example the handling and assembly of large parts. Moreover, these teams of production units should be formed in an ad-hoc manner since each individual unit may also be assigned to other, smaller tasks. As a consequence of this ad-hoc team formation, there is also the need to set up, use and break up their related control loops.

Such temporary control loops require dedicated infrastructure services, including safe services for their activation, their execution, their inner communication, and their deactivation. Additionally, situations are expected to occur where control loops must be switcheable and re-configurable, e.g. when a new team member joins.

2.2.4 Integration of Dynamic Models

Previous research on control of industrial robots reports about advantages of model-based control concepts for tracking of trajectories [SS00]. The same applies to robot cooperation that involves dynamic models in the respective control scheme [DMZ91, ZV06]. Since the scenario under investigation asks for cooperation of production entities, a suitable piece of software is required to provide the infrastructure for such implementations [GFM02].

The models involved may be of centralized or distributed nature. The centralized case requires one processing entity that hosts the whole model, whereas, in the distributed case, each of the entities carries a dedicated fraction of the model.

2.2.5 Communication Paths

The choice of communication paths has to account for the mobility of the production units. Note that communication paths have to be established dynamically. For example, when a new production entitiy joins a team, or when a new team is formed, suitable communication paths need to be established. The entities' mobility motivates the proposal to use wireless communication. Though convenient in many aspects, this choice raises the issue of restricted/varying bandwidth. If such a channel is part of a closed control loop, its latency adds to the phase delay of the control loop. Consequently, since the latency in wireless communication networks may vary, the phase delay and also the phase margin are also subject to variation. It is of even more importance to garantuee robustness of the whole system with respect to communication failure. Loss of communication may degrade performance but must not in any case endanger stability of the overall process.

The proposal stated in the subsequent section takes this issue into account by introducing a dedicated layer for control loops with varying latency.

2.2.6 Documentation for Quality Management

It is intended to integrate documentation facilities into the production system to document the production process. The recorded data, which may be taken during or straight after particular critical production steps, may serve as a data basis for quality monitoring and control. It may also be helpful for the certification procedure in order to meet aircraft quality standards (e.g. EN 9100). This argument recommends the implementation of monitoring components (Hardware and Software) to supervise the production process. For example, there may be dedicated robots that are solely occupied with documentation tasks.

3 Integration of Agent-Based Systems into Multi-Layered Control Infrastructures

3.1 Relevance of Agent-Based Control for the Scenario Under Investigation

In production automation, it is a common approach to divide the control problem in hierarchical layers [Pri06]. Especially if the plant to be controlled is large, hierarchical structures, having sub-functionalities encapsulated in subordinated control computers, become favorable.

The more functionalities such a subordinated controller, e.g. a robot control or NC-control, receives, the more autonomously it can carry out production tasks.

After the increase of the autonomy of production cells, elements of artificial intelligence have been introduced to production systems. They are intended to adapt the system's capabilities automatically to shifted requirements. The project behind ([Bre12], Chap. 6) is an example for such approaches, showing in detail how agent-based systems can be used to steer automated assembly processes.

There is, for example, improvement of the behavior over time by means of artifical learning of cooperating agents. Also, adaptation to shifted output targets (fast assembly vs. precise assembly) is shown. The cited work shows that agent-based structures are capable to control complex production scenarios, and hence considered also in the present work.

The capabilities of this system, namely abstraction, self-configuration, scalability, learning and fault tolerance, motivate the authors to propose agent-based structures to control the scenario outlined in Sect. 2. Especially, the scalability is an interesting aspect, since it is likely that a large production system as sketched in Fig. 1 evolves in multiple evolutionary phases. In each phase of this evolution, development of new production entities is expected, either extending the production system or substituting previously existing entities. Agent-based concepts inherently support this development process, since the incremental effort for such evolutions can be expected to be rather small compared to conventional hierarchical control: since the communication relies on an abstract task description language, there is only the need to connect the new entity to the other agents, and the infrastructure takes care to integrate the new entity. If such infrastructure is available, it is expected that the effort required to scale up the production system from just a few entities to full size is remarkably low.

Agent-based production planning has been investigated previously [YS08, vBWV+98], but its industrial implementation in the context of aircraft manufacturing is still to be shown [ARR04]. Mainly, planning remains a manual task there.

Other concepts for planning of aircraft manufacturing have been brought into practice, where product design already considers the production process [SH00].The present work aims at the realization of such methods.

Agent-based control is already mature enough to be attractive for commercial applications in warehouse logistics [BCMC08, WDM08, TJR+09]. In contrast, none of the reviewed literature ressources reports about such a level of commercialisation in the context of production. Yet, researchers contribute towards this goal, presenting more and more holistic control approaches [vBWV+98] to provide a desirable environment for the realization of agent-based control. But there are still open challenges remaining, for example semantic extensions of agents that improve the complexity of decisions that can be made [VROM09]. The cooperation behind the present paper intends to contribute to this topic, too, in order to help agent-based systems make it into practice.

Dias et al. [DZKS06] give a comprehensive overview of the capabilities of market-place agent systems to coordinate complex multi-robot missions. The authors of the present article share the opinion of the cited work that "while many multirobot coordination approaches have been proposed, market-based approaches in particular have been proven effective". On the basis of this argument, there is a so-called *market place* dominating the control architecture. The name *market place* describes how the self-contained agents act inside a virtual economy. This economy assigns a certain worthiness to available ressources and tasks to complete, and both elements are subject to trades. For example, auction-like negotiations may take place to find a best possible solution among a set of bidding agents. An agent who wins an auction receives the worthiness of the respective task, but has also to pay for the ressources it uses.

In summary, agent-based control appears viable for control of complex, scalable, and changeable production systems that feature mobile production entities. Literature shows that many aspects of agent-based planning and control have been investigated thoroughly, and their application to production scenarios has been tried recently. Some of them already gained great maturity and complexity, whereas some still lack their proof in applications. However, none of the considered literature ressources reports about a scenario where both, workpieces and production units are mobile.

In terms of implementation, it is widely accepted that the use of a middleware is advantageous in order to mask hardware and communication issues from the application [SSK08]. This helps during implementation, test and runtime, especially, when heterogeneous and distributed platforms have to be operated in one control system [Tho10]. These favourable properties are also included in the concept elaborated in Sect. 4, to establish transparency across system borders of the entities.

3.2 Organisation of Components in Hierarchies

The following proposal is based on the results of previous research, where hierarchical architectures proved to be successful. According to the investigation in [DMRH10], control concepts and infrastructures for robot control[1] use hierarchy layers for *one* particular purpose only. More specificially, hierarchy layers are used to represent *either* organizational relations (component perspective) *or* aspects of timing (timing perspective). Both paradigms have been shown to be viable in projects related to the given citations, and each of them yields advantages over the other. Under the expectation to join the favorable properties of both paradigms, it was proposed in [DMRH10] to join these targets. The cited work also reports about successfull design and implementation of this enhancement for the control of parallel kinematic machines. The present article adopts and extends the scope of these findings and proposes to apply this idea to whole production systems. Three principles guide the design process:

1. Control loops should be recognizeable.
2. Components may be executed concurrently.
3. Invariance of the architecture with respect to both, the function and the realtime requirements, has to be provided.

In order to describe the architecture and its components, it is necessary to consider both the component perspective and the timing perspective. In accordance to the UML (Unified Modelling Language), the model of the architecture consists of its perspectives; hence, both perspectives have to be taken into account in order to understand its mechanisms.

4 Top-Level Design of an Agent-Based Control Architecture

Having the mechanisms of the market-place in mind, the top-level architecture in Fig. 2 has been designed. The market place represents a runtime environment for a multi-agent system. The market place is hosted centrally, e.g. on a dedicated server. Agents may participate in this market place to offer their capabilities via bids. An agent may have an external interface to communicate with an external entitiy, for example a production unit. In this way, each production unit has a representative agent within the market place.

The following sections describe the concept and discuss some considerations for its upcoming implementation.

[1] *ORCA2* [BKM08], *Player* [Pro08], *SFMIDDLEWARE* [JNH06], *CLARAty* [NJ12], *MIRO* [USEK02], *OpenRDK*, *MARIE* [Cô08], *MiRPA* [FKK^{+}07], *OROCOS* [Bru08], *OSACA* [TOPC10], *MCA2* [FZI08].

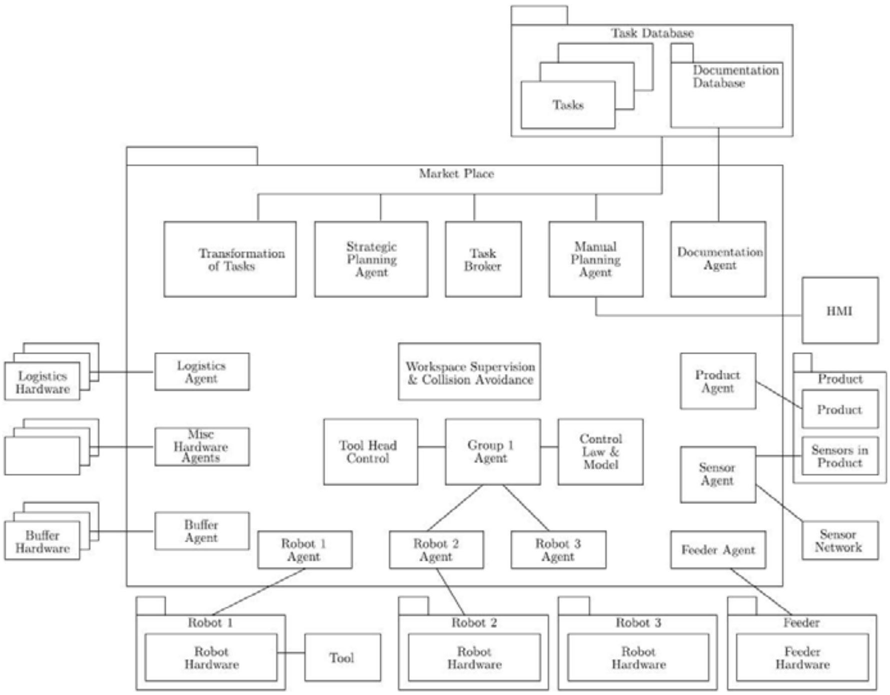

Fig. 2 Component perspective on proposed architecture: market-based multi-agent system and exemplary hardware entities (simplified collaboration diagram, in similarity to UML 2.0)

4.1 Component Perspective

4.1.1 Components Outside the *Market Place*

The *task database* is a dynamic server, that contains an assembly graph at the beginning. This graph is, at this stage, only dependent on the product. In this state, it is not specified detailed enough for the execution. There are many degrees of freedom left, which must be specified prior to execution (which is a task of the planning agents).

4.1.1.1 Task Database & Documentation Database

For low-level tasks, the concept of skill primitives is a suitable description of robot tasks [DMRH10]. Tasks on a more abstract level require other concepts, since more meta information about the task has to be stored. These two types of task descriptions must be related to each other. It is proposed to use a hierarchical relation, where the abstract task description is superior over the low-level task description.

The *documentation database* is there to record the tasks carried out and the process data which is relevant for quality management. Along the progress of the production process, this database is filled more and more. Links between the recorded data and their respective tasks are created, which makes this data searchable for monitoring and automated quality correction.

For the purpose of documentation the low-level tasks are extended by an annotation for quality management. First, in extension to [DMRH10], a skill primitive may carry a command, which specifies the variables to be recorded. Second, during execution, the skill primitive in the database is extended by the data recorded. This low-level quality measurement may be cumbersome to navigate in, since the amount of data may grow rapidly. For this reason, again, a hierarchical model is applied: The low-level documentation is condensed to a summary that is attached to the respective task description on the superordinated level.

4.1.1.2 Other Elements

Outside the *market place*, there are other components which represent the external units. Such units may be robots, feeders, logistics support, buffer storages, recharging stations and dedicated sensors. Each of these units may have a dedicated control system, e.g. the robots may run proprietary control software.

4.1.2 Components Inside the Market Place

4.1.2.1 Elements Related to Planning

Inside the *market place* (top row) there are the agents depicted which are concerned with planning (*transformation of tasks*, *strategic planning agent*, *manual planning agent*, *task broker*)[2]. There, auctions take place involving the planning agents and other stakeholders of this process, e.g. robot agents. If tasks need further specification before they can be scheduled, the *transformation of tasks* will be called to cover these tasks. They may be supported manually via the *manual planning agent*, which is interfaced to the *human-machine interface* (*HMI*). The *strategic planning agent* can be considered as the instance which does online-replanning of tasks sequences, in case there are unforeseen changes. Also, the *strategic planning agent* and the *transformation of tasks* are responsible to negotiate the best choice for a sequence of tasks with other stakeholders (e.g. robot agents offering specialized skills). The *task broker* offers well-specified tasks to be carried out on the *market place*. Control agents can bid for these jobs and negotiate the best strategy in this way.

[2] The planning algorithms and more details about the agent-based implementations are subject of [HWH+11].

4.1.2.2 Elements Related to Control and Documentation

Each external unit has a representative agent inside the *market place*. This agent provides at least communication services between the *market place* and the control software onboard the external unit.

According to this pattern, each robot has its own *robot agent*, which communicates low-level tasks towards the robot. This pattern is applied in the same way to feeders, storages and other external devices.

This agent also applies for jobs, that can be carried out by the robot represented. For example, multiple robot agents apply for a particular job. The agents of the logistics and feeder hardware try to contribute to this job and support the robots. The *task broker* then assigns the job to those applicants which do the job in an optimal way. If a job is only feasible for a team of robots, a *group agent* may apply for that job. Such an agent is capable of coordinating multiple robots. It contains the coordinated *control laws and models* and has control over special tool abilities, if applicable.

4.2 Timing View on the Components

The functionalities contained by the components described above may be executed in multiple timing contexts. For example, the parametrization and the management of motion generators may be executed in an event-driven scheme, whilst the trajectory of the motion has to be provided on a fixed cyclic base. In enhancement to [Maa09, DMRH10], where a three-layered design was identified to be a suitable approach for robotics, the present work proposes four layers. Each of them follows a particular execution scheme. Particularly, the additional layer (Layer 2) contains control loops under soft realtime constraints. This is necessary since wireless communication is expected to vary in latency, as explained above. Figure 3 shows the hierarchy and gives an impression of the most important data flows.

4.2.1 Integration of Market Place into Multiple Layers

A component displayed in Fig. 2 may be present in multiple timing layers. Consider the market place as an example of this pattern: it possesses multiple threads or processes, Each of them is scheduled in a specific timing context. In this way, negotiation services may be provided in multiple timing layers. Accordingly, each agent may possess multiple threads/processes. Each of the threads/processes, being dedicated to a specific timing layer, interfaces with the respective thread/process of the market place. This pattern gives a component the ability to feature internal cross-layer interaction and to contribute to multiple timing contexts. In brief, the market place stretches across multiple layers.

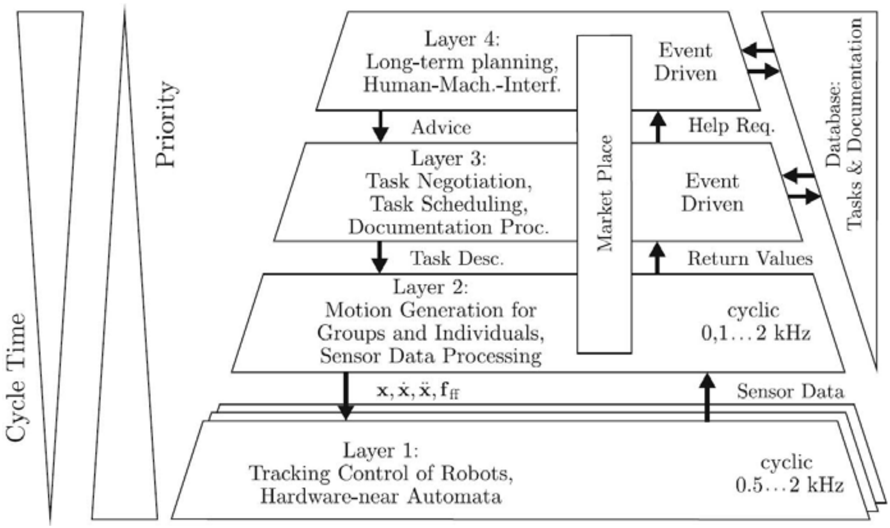

Fig. 3 Hierarchical organisation via context layers

1. Layer: The first layer contains control contexts that require hard realtime execution. Here, hard realtime shall be understood as a strict deadline that must be met by the algorithm considered. Violation of the deadlines causes a severe error.
   For example, this layer covers low level trajectory generation and tracking control of robots. This layer may contain several control contexts, which means that also several cycle times may be present. The control contexts may run in a cascaded scheme or with any other coupling that is required by the control concept in place. Also, the contexts of this layer may run distributed on multiple hosts. In this structure, suitable synchronisation mechanisms must be implemented.
2. Layer: Realtime restrictions also apply to the second layer. In this case, deadlines are applied to algorithms, too, but there are predefined cases of deadline violations that the system has to cope with. The intention of this construct is that communication channels may be used where the quality of the transmission varies. In this context, the latency of messages is subject to uncertainty. Consequently, a targeted deadline may be exceeded with some probability. Then, the design of the second layer ensures that deadline violations may degrade the performance of the system only, while the stability of the process is not endangered. This principle may be used to realize outer control loops, which feed cascaded tracking control, e.g. for grouped robots.
3. Layer: In contrast to the cyclic execution of the first two layers, the third layer is event-driven. This is where the core components of the *market place* are located. For example, the components for planning and scheduling are located, as well as robot agents that take their part in the negotiation of planning and scheduling.

4. Layer: The lowest priority is set on the fourth layer. It serves as a background task where miscellaneous tasks are carried out. For example, long term planning, monitoring, user interaction and background services run here.

4.3 Middelware and Communication

An infrastructure is required on top of which the four layers are built. The usage of a middleware is common for this purpose of hardware abstraction, for communication services and for resource management. A name service simplifies the establishment of dynamic communication paths. The realtime constraints of layer one and two ask for support of fast message passing and shared memory services. Additionally, if multiple hosts are involved, inter-host synchronisation schemes must be available in the realtime context considered. Detailed overviews, benchmarks and discussions of favorable middleware packages are given in [Maa09, Tho10]. Another comparison and an implementation of an agent-based system is presented in [SSK08].

4.4 Tracking Control Using the Task Frame Concept

Trajectory control shall take place using the task frame concept [MHK06, DMRH10]. It is favorable here, because the trajectory generation can be specified in a task-oriented coordinate system (which also may be anchored to the coordinate system of the end effector of a production unit). Then, this coordinate system is placed at the location where the actual task shall be carried out. In this way, global tolerances of the location of a particular assembly situation (which may occur at big workpieces) can be compensated easily in a local manner and moving coordinate system can be used easily. Inherently, the task-frame concept encloses industrial standards of trajectory description as a subset. On top of that, the concept of skill primitive allows tasks to be executed conditionally, which simplifies the description of alternative actions.

5 Summary and Outlook

This article assumes that the production of primary structures made of carbon fibre reinforced plastic will benefit from parallel execution of tasks. To achieve such parallelization, a consortium affiliated to RWTH Aachen, DLR Braunschweig and TU Braunschweig currently prepares a new design concept. The present article contributes an architecture to control the production within such a scenario. A market-based multi-agent system is proposed, containing elements to plan, schedule and coordinate the execution of the production. The architectural model is shown from the components perspective and the timing perspective.

In contrast to previous production control concepts the system outlined here also takes the mobility of production units into account. This novelty is motivated by the fact that the assembly situations are located across a large workspace.

Since quality management is of high importance for aircraft manufacturing, documentation of tasks carried out is important as well. In this article, a principle is proposed where the task description is extended by data relevant for quality management, e.g. dedicated measurements of assembled parts.

In brief, this article provides a top-level view on an agent-based control architecture for scalabe production systems. It is intended to provide a platform that helps the consortium to elaborate and demonstrate the variety of technologies related to the outlined scenario. At the same time, the questions occuring with the scale-up of such a complex production system will be investigated at the proposed concept.

Plans for future work contain the elaboration of the details of the architecture. This investigation will also work on design patterns that simplify the scale-up from a small implementation to a holistic manufacturing platform. This scalability allows the system to be developed in multiple stages, from a small implementation for the demonstration of new technologies up to a full-size manufacturing platform.

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A Graph Based Hybrid Approach of Offline Pre-Planning and Online Re-Planning for Efficient Assembly Under Realtime Constraints

Daniel Ewert, Sebastian Thelen, Ralph Kunze, Marcel Mayer, Daniel Schilberg, Sabina Jeschke

Abstract Assembly tasks, e.g. the assembly of an automobile headlight, are a big challenge for nowadays planning systems. Depending on the problem domain, a planner has to deal with a huge number of objects which can be combined in several ways. Uncertainty about the outcome of actions and the availability of parts to be assembled even worsens the problem. As a result, classic approaches have shown to be of little use for reactive (online) planning during assembly, due to the huge computational complexity. The approach proposed in this paper bypasses this problem by calculating the complex planning problems, e.g. which parts must be mounted in which sequence, prior to the actual assembly. During assembly the pre-calculated solutions are then used to provide fast decisions allowing an efficient execution of the assembly. Within this paper this online planning combined with offline planning and the assessment of realtime constraints during assembly could be executed in the future will be described.

Key words: Assembly Sequenze Planning, Automated Assembly Planning, Cognitive Sssembly Control

1 Introduction

1.1 The Polylemma of Production Technology

In the last years, production in low-wage countries became popular with many companies by reason of low production costs. Hence, competitive production engi-

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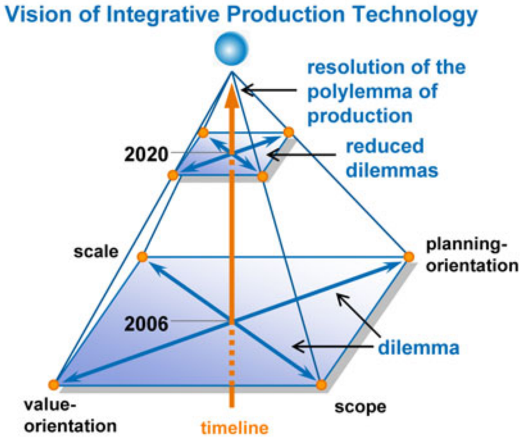

Fig. 1 The polylemma of production

neering is particularly important for high-wage countries such like Germany. Competition between manufacturing companies in high-wage and low-wage countries typically occurs within two dimensions: the production-oriented economy and the planning-oriented economy [Bre07].

In the dimension of the production-oriented economy low-wage countries' production compensates possible economic disadvantages within process times, factor consumption and process mastering by low productive factor cost. Companies in high-wage countries try to maximize the economies-of-scale by the usage of relatively expensive productivity factors. These disadvantages of relatively high-unit cost high-wage countries try to compensate through customizing and fast adaptations to market needs – the economies-of-scope. In addition the share of production within the value chain decreases more and more. Thus, the realizable economies-of-scale decreases, too. The escape into sophisticated niche markets is not promising, either.

Within the second dimension – the planning-oriented economy – companies in high-wages countries try to optimize processes with sophisticated, investment-intensive planning and production systems. Since processes and production systems do not reach their limit of optimal operating points, additional competitive disadvantages for high-wage countries emerge. In contrast, companies in low-wage countries implement simple, robust value-stream-oriented process chains [Klo09].

The production industry in high-wage countries is confronted with these two dichotomies mentioned above. On the one hand there is the dilemma value orientation vs. planning orientation and on the other hand the dilemma scale vs. scope. These two dilemmas span the so called polylemma of production technology as shown in Fig. 1 [Bre07].

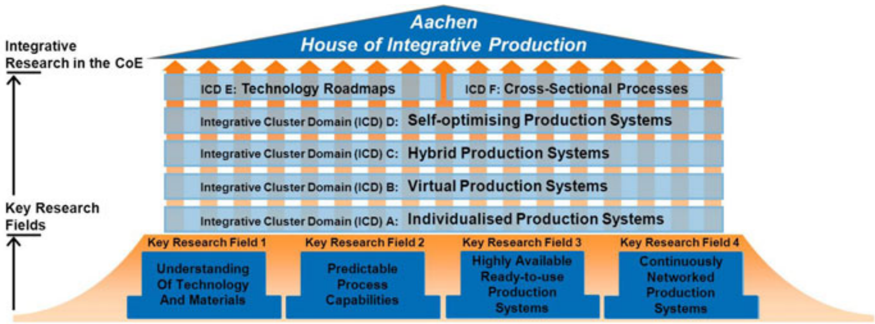

Fig. 2 The Integrative House of Production

1.2 Cluster of Excellence "Integrative Production Technology for High-Wage Countries"

The Cluster of Excellence "Integrative production technology for high-wage countries" unites several institutes of the RWTH Aachen University, which are dealing with production engineering. 19 professors of RWTH Aachen University, who work in materials and production technology, as well as affiliated institutes such as the Fraunhofer Institutes, work in this cluster with the objective to contribute to the maintenance of production in high-wage countries which is relevant for the labor market. With regard to economy, focus is on products that address both niche markets and volume markets. The solution for the problems addressed sometimes require a fundamental new understanding of product and production technological contexts.

The Cluster of Excellence aims for the development of basics for sustainable production-scientific strategy and theory, as well as for the necessary technological approaches. Based on the scientific analysis of the polylemma of production technology, the individualisation, virtualisation and hybridisation, as well as self-optimisation of production technology were identified as areas in need for action. Therefore, four major fields of research have been defined: Individualised Production Systems, Virtual Production Systems, Hybrid Production Systems and Self-optimising Production Systems. Institutions and participants of the same field of research become strategically consolidated in so called Integrative Cluster Domains (ICD) related to their competences in production technology at RWTH Aachen University. These ICD form the Aachen House of Integrative Production (see Fig. 2).

This paper deals with cognitive planning and control systems of production which are addressed in a sub-project of the ICD-D "Self-optimising Production Systems".

2 The Subproject "Cognitive Planning and Control System for Production"

2.1 Objective

An advanced rationalization of production systems and processes is typical for high-wage countries. A significant challenge is to involve the implementation of value stream-oriented approaches along with simultaneously increasing planning efficiency. A promising approach for the reduction of previous planning efforts consists of the development of a production system that is able to autonomously plan the production during a running process. Furthermore, such a system could autonomously react to changes in customer demands.

Within this sub-project a cognitive planning and control unit (CCU) is developed that aims to automate the assembly planning process, so that only a CAD description of the product which has to be fabricated is required as input to the system [HGI08]. By means of this unit it will be possible to increase the flexibility of manufacturing and assembly systems and to decrease the planning effort in advance.

2.2 Approach

The task of the CCU is to plan and control the assembly of a product which is described solely by its CAD data. The system plans and executes the assembly autonomously, after receiving further descriptions, which are entered by a human operator. The CCU cooperates with human operators during the entire assembly process. While most of the assembly actions are executed by the assembly robot, certain tasks can only be accomplished by the operator.

The presented approach is evaluated within a scenario which is depicted in Fig. 3. The setup contains a robot cell with two robots, in which one robot (robot 2) is only controlled by the CCU [KHB09, HGH09]. The other robot (robot 1) delivers separate parts for the final product in random sequence to a circulating conveyor belt. The CCU decides whether to pick up the delivered parts or to refuse them. If a part got picked up, the parts will be put into a buffer area or into the assembly area for immediate use.

Due to the random block delivery future states of the system cannot be predicted. The CCU is therefore facing a non-deterministic planning problem, requiring either an online re-planning during the assembly, whenever a not expected event occurs, or a plan in advance for all possible delivery sequences. Each of these strategies results in extensive computations, which lead either to slow responses during the assembly, or an unacceptable amount of pre-planning. The approach proposed in this paper therefore follows a hybrid approach, based on state graphs as described in the remainder of the paper.

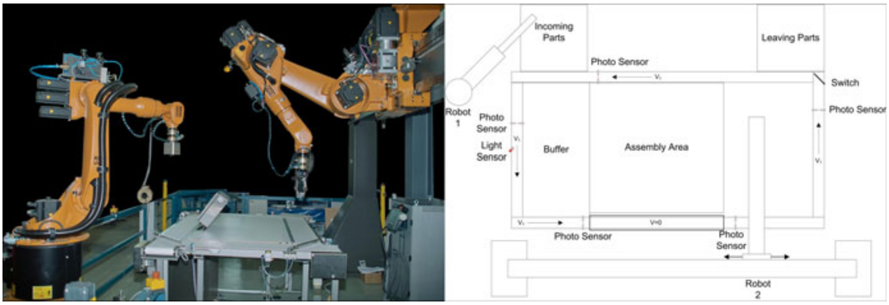

Fig. 3 Photo and diagram of the robot cell

3 Graph Based Planning Under Realtime Constraints

3.1 Related Work

In the field of artificial intelligence, planning is of great interest. Several different approaches do exist, which are suitable for the application on planning problems. Hoffmann et al. developed the so called Fast-Forward Planning System, which is suitable to derive action sequences for given problems in deterministic domains [Hof01]. Other planners are capable to deal with uncertainty [HB05, CGTT01]. However, all these planners rely on a symbolic representation based on logic. Thus, the corresponding representations of geometric relations between objects and their transformations, which are needed for assembly planning, become very complex even for small tasks. As a result, these generic planners fail to compute any solution within acceptable periods of time.

Other planners have been designed especially for assembly planning. They directly work on geometric data to derive action sequences. A widely used approach is the Archimedes System [KWCA96] that uses AND/OR Graphs and an "Assembly by Disassembly" strategy to find optimal plans. U. Thomas follows the same strategy [Tho08]. But where the Archimedes System relies on additional operator-provided data to find feasible sub-assemblies in his solution, Thomas uses geometric information of the final product as input only. However, both approaches are not capable of dealing with uncertainty.

3.2 Basic Idea

To allow fast reaction times during assembly the planning process is separated into an offline part(the Offline Planner, described in Sect. 3.3), executed prior to the assembly, and an online part(the Online Planner, described in Sect. 3.4), executed in a loop during the assembly. The resulting system is drafted in Fig. 4. While the

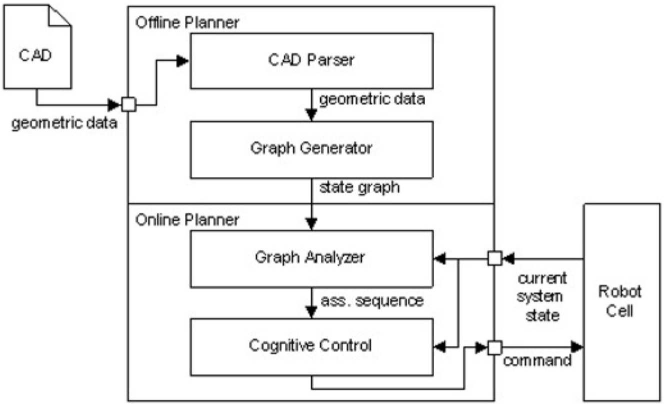

Fig. 4 System Overview of the CCU

Offline Planner is allowed computation times of up to several hours, the Online Planner's computation time must not exceed several seconds. The task of the Offline Planner is the precalculation of all feasible assembly sequences leading from the single parts to the desired product. The output is a graph representing these sequences, which is transmitted to the Online Planner. During assembly the Online Planner then repeatedly maps the current system state to a state contained in the graph. Following, it extracts an assembly sequence that transforms this state into a goal state containing the finished product.

This assembly sequence is then handed to the Cognitive Control component which triggers the accordant robot commands, interacts with the human operator and reacts to unforeseen changes in the state. Thereby, it is not bound to follow the given assembly, for example it can decide to invoke actions that move blocks from the conveyor belt to the buffer and vice versa instead of continuing an assembly. The details of the described process are discussed in the following sections in particular.

3.3 Offline Planning

3.3.1 Graph Generation

During the offline planning phase, a solution space for the assembly sequence planning problem is derived from a product description. The current approach relies on a description of the assembled product's geometry and its constituting parts, possibly enriched with additional mating directions or mating operation specifications. Based on this information, an "assembly by disassembly" strategy is applied to ultimately generate a state graph that can be efficiently interpreted during online planning [HdMS91]. The main concept of this strategy is a recursive analysis of all possibilities of an assembly or subassembly, in which any assembly or subassembly is being separated into two further subassemblies until only nonseparable parts remain.

The geometric data is read by the CCU from a CAD file and stored in a tree data structure that is used to represent the product's assembly related properties. This assembly model tracks each atomic part that can not be disassembled further with a separate identity. These objects are reused in the assembly graph and reference all properties including the geometry of the represented part. To describe functional aspects like a thread or face of such a part, assembly feature instances can be used. This is relevant, if additional data beside the part geometries shall be taken into account by the assembly planner.

3.3.2 Evaluation of Assembly Separations

While the CCU logically disassembles the complete assembly, multiple calculations have to be performed on each separation:

- The feasibility of the separation has to be estimated.
- The assembly plan for the resulting assembly operation has to be calculated.
- A static cost for the assembly operation has to be assigned, which later will be utilized by the online planner or the graph pruning algorithms.

These operations are performed by an evaluation pipeline built from multiple *separation evaluators*. This enables later additions of evaluation operations and encapsulates all evaluation done on a single separation. In [Tho08] an algorithm for pure geometrical inference on assembly parts is depicted. This algorithm is used for evaluation, if a separation can be performed at all. Furthermore, it delivers a set of assembly directions from which the assembly plan for an operation can be generated. Following Kaufman et al. [KWCA96], the results from the geometric inference are additionally enriched with possible userdefined overridings that have shown to be necessary for complicated geometries like screws or threads. They provide a way to drastically enhance the resulting assembly plans.

To enable this mixing of geometric inference and predefined mating directions, the geometric analysis of a mating operation is separated into two steps. In the first step, only the geometries of assembly parts which change contact state when the operation is performed are taken into account. Even if this processing yields no viable mating directions, but there is at least one that is predefined by the user, the processing is carried on without directly discarding the separation in graph building. The second, global geometric inference takes the complete subassemblies of the separation into account. If the geometric inference from the first step labeled user defined mating directions as blocked the responsible geometric features are masked from each other to suppress their lokal blocking behavior.

The resulting evaluation pipeline is shown in Fig. 5. A separation is only excluded from the assembly graph if it is evaluated as being impossible to perform. This contrasts to other approaches like [Tho08] and [DYW93] where graph pruning heuristics are used to reduce computational demands and the utilized solution space. To enable the online planner to react upon unforeseen assembly states or events the

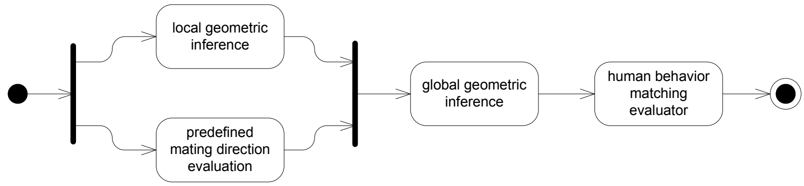

Fig. 5 The current computations performed to evaluate and rate a separation

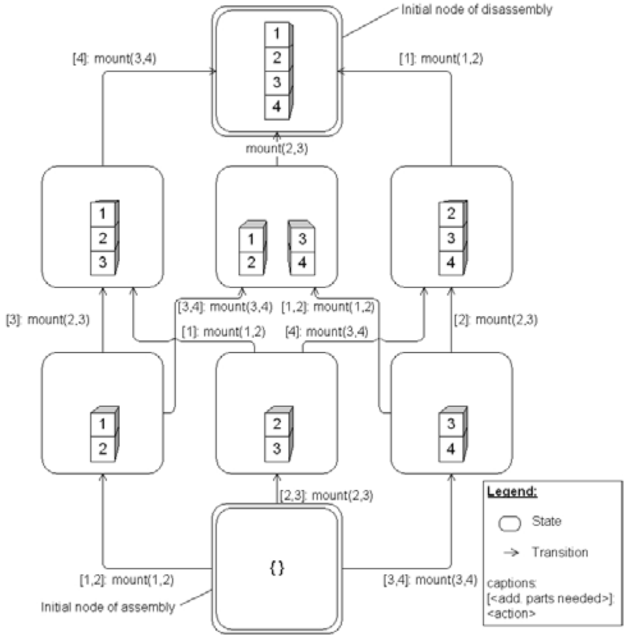

Fig. 6 Example of a state graph representation

complete solution space has to be processed. Though, high costs might be assigned to separations that should be avoided, as is discussed later in this section.

Where actual online planning relies on a state graph representing the solution space, the graph builder initially constructs an AND/OR Graph representing all viable assembly operations and states, that might appear [HdMS91]. A state graph, as shown in Fig. 6, is then derived from that graph in a second step. This conversion is necessary, because the planning algorithm which is used during the online phase is not capable to handle the AND/OR Graph, which is a directed hypergraph.

All data, which is generated by the separation evaluators for a separation, is stored in the AND/OR Graph's respective hyperarc. Currently, this information contains static operation costs and mating operation descriptions for each assembly, that might be active (e. g. moved) during the assembly step represented by the edge. The state graph is created in such a way, that its transitions/edges are directed in the opposite direction of the AND/OR Graph's hyperarc they originate from. Each state only contains the passive assembly to which other parts may be added. The availability of the active parts is encoded as condition for a transition which contains the operations static cost and mating operation description.

3.3.3 Increasing Machine Transparency by Mimicking Human Behaviour

Mayer et al. found that assemblies executed by human individuals follow – in most cases – simple rules [MOF+09]:

- Parts are placed next to each other. In other words, two separate subassemblies are not constructed in parallel.
- Structures are built layer by layer from bottom to top.
- Assembly begins at the boundary of the desired product.

During graph generation, each state is evaluated regarding its consistency with these (or similar) rules and receives an accordant rating. In the later phases of the online plan generation these ratings are taken into account and states with better ratings are preferred to other states. This strategy allows the CCU to mimic human behavior to a certain level.

3.4 Online Planning

3.4.1 Responsibilities and Workflow of the Online Planner

The Online Planner is responsible for deriving plans during the assembly. Therefore it uses the state graph provided by the Offline Planner and current information about the robot cell's situation. This approach is similar to a system developed by [ZW08], which reactively generates assembly task instructions for a human worker. The general process of the plan derivation from the state graph is depicted in Fig. 7.

The Graph Analyzer receives the generated state graph from the offline planning phase. It then has to pause until the Cognitive Control sends the actual world state describing, which contains the current situation of the assembly. The Graph Analyzer maps this world state onto the matching state contained in the state graph, now the "is-node". If the is-node is identical to the goal-node, the node containing the completed assembly, the assembly has been completed and the process ends. Otherwise, the current world state is compared to the previously received world state. If new objects have occurred since the last run, the graph is being updated. This process is detailed in the section "update phase". After the graph has been updated, the optimal path from the is- to the goal-node is calculated as described in section "sequence detection". The found path represents the optimal assembly plan for the given current situation. It is sent to the Cognitive Control component, which then executes the assembly.

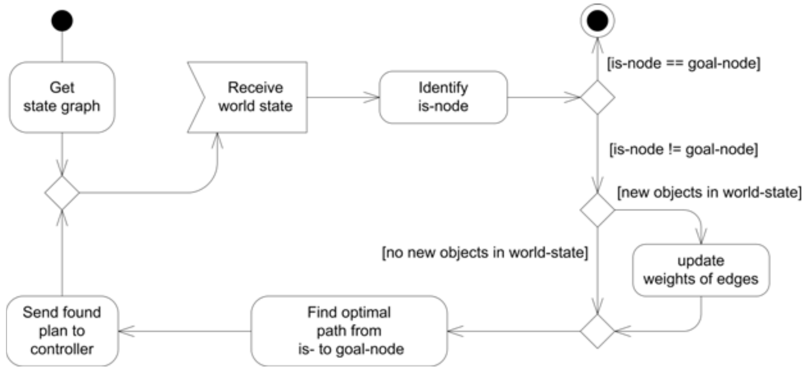

Fig. 7 Workflow of the Online Part

3.4.2 Update Phase

In this phase, dynamic costs are assigned to the state graphs edges. The cost of an edge depends on the static costs of the assigned action and costs depending on the availability of required parts. Here, robotic actions allocate lower costs than actions that must be executed by the human operator. Actions that rely on parts which are currently not available receive penalty costs. Due to this weighting of actions the Online Planner prefers currently realizable assemblies before assemblies that rely on parts, which are currently not present. However, reducing the penalty costs so that it becomes possible for a sum of realizable actions to outweigh the cost of one unrealizable action introduces speculation in the planning process: The algorithm could now choose to prefer a short but yet not realizable sequence over a realizable that needs much more actions to fabricate the final product. This decision could turn out to be better, if the missing part is delivered to the assembly before the previously not realizable action is to be executed. This behaviour can be facilitated even more by assigning penalty costs depending on the distance of the action in question to the current state. Considering time: The further away the action to be executed, the lower are the penalty costs it retrieves.

3.4.3 Sequence Detection

The algorithm identifies the node of the updated graph which is matching the current state of the assembly. This node becomes the initial node from which an optimal path to the final node has to be calculated. This is achieved using the A* search algorithm [HNR07]. A* chooses nodes for expansion with a minimal value for $f(x) = g(x) + h(x)$, where $h(x)$ is a heuristic for the distance from node x to the goal node, and $g(x)$ represents the present path costs. Here, $h(x)$ takes into account the number of not correctly mounted parts as well as the "performance" of the node during its evaluation as described in Sect. 3.3. The path costs g are calculated as the sum of the costs of the traversed edges plus the costs for every necessary tool change along that path. The alteration between actions executed by the human operator and actions done by a robot also counts as a tool change, resulting in a preference for assembly sequences where human involvement is concentrated in single time slots.

3.5 Realisation of the Assembly

The actual assembly is realised by the Cognitive Control component. It is based on Soar, a cognitive framework for decision finding that aims on modelling the human decision process [LNR87]. It is responsible to invoke accordant actions based on the current world state received from the robot cell and the assembly sequence sent by the Graph Analyzer. The default behavior of the Cognitive Control is to realize the given assembly sequence by invoking the accordant robot command or instructing the operator. In case of unforeseen changes to the world state, due to a delivery of an object, it decides whether to discard or store the new object, depending on if the object can be used in later assembly steps. In such a situation the Cognitive Control can request a new plan from the Graph Analyzer which regards the new object. The component is also responsible for dealing with failure, e.g. failed robot actions or similar.

4 Outlook

Empiric studies need to show the capability of the described approach to accomplish feasible assembly sequences for different products of varying complexity. It is to be determined, which weightings of realizable and not realizable actions lead to optimal results. Furthermore, research on how much graph pruning influences the average computation time is required, and if the gain in time is worth the risk of missing an optimal assembly. Additionally, the scalability and applicability of the approach to industrial use cases has to be examined.

5 Conclusion

The polylemma of production can be alleviated by incorporating automatic planning systems. Depending on the assembly setup, these systems have to face nondeterministic behaviour during the assembly, which increases the computational complexity by orders of magnitude. The presented approach follows a hybrid approach of offine pre-planning and online re-planning to deal with this problem under realtime constraints. The actual planning problem is solved prior to the assembly by generating a state graph that describes all possible assemblies of the intended product. This graph is updated during the assembly and at this time optimal assembly sequence is extracted. This process is by far less time consuming and allows a fluent assembly. By taking into account the human behaviour during assembly it is possible to speed up the graph generation. Situations during an assembly that would not occur during an assembly executed by humans are pruned from the graph. This results in reduced computation times and increased machine transparency by meeting human expectancy.

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Innovative Capability – Learning Capability – Transfer Capability. Promoting Innovation Systematically

Max Haarich, Sylvia Sparschuh, Claudio Zettel, Sven Trantow, Frank Hees

Abstract The article "Innovative capability – learning capability – transfer capability. Promoting innovations systematically" provides an overview of the contents, structure and management of the BMBF research program on "Working – Learning – Developing Skills. Potential for Innovation in a Modern Working Environment". The object of research innovative capability shows heterogeneous prerequisites for generating innovations and forms of appearance which require more flexible and more specific funding instruments. It is shown that promoting innovative capability is inextricably linked to increasing the learning capability and transfer capability of the funding program itself. The BMBF is responding to these requirements with open program structures that support inherent learning and transfer capability in order to address the changing challenges efficiently and in good time. The contribution of the monitoring and meta-projects to producing this learning and transfer capability of the program is then shown in conclusion.

Key words: Innovative Capability, Knowledge Transfer, Collaborative Research

1 Introduction

Germany is the land of innovations. Hardly any other industrial nation has generated such a high proportion of added value with research- and knowledge-intensive products and services. Innovative companies, training, research and technology therefore

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form the bedrock for Germany's position in the international competitive arena and the basis for its affluence and employment.[1]

However, innovations must be measured against the extent to which they contribute to social progress and economic success [fBuF07a]. They are normally successful and effective in the long term if the interaction between people, organization and technology is effective (cf. [Bul06, THJ11]). Against the backdrop of global scarcity of resources and the opening up of powerful economies on the international market, the major challenge for Germany is to strengthen and sustain this power to innovate [Wis09].

For this reason, innovative capability is a fundamental requirement which is inseparably linked to competent people and versatile companies. HR, organizational and skill development therefore carry equal weight in a comprehensive innovation management system and are thus firmly anchored in the horizontal objectives of the High-tech Strategy [fBuF06]. Innovative capability is strongest in companies that challenge and support people in the work process. In this process, a high priority is afforded to practical and research activities concerned with Preventive Occupational Health and Safety as well as the effects of demographic changes in the working environment. These topics therefore build a focus for the research and development program "Working – Learning – Developing Skills. Potential for Innovation in a Modern Working Environment" of the Federal Ministry of Education and Research (BMBF).

The goals of this BMBF program are closely related to the goals of the High-tech Strategy. The funding program thus helps to shape the framework conditions that lead to comprehensive innovation strategies for different users. The program focuses in particular on enabling German companies (particularly SMEs) and institutions to respond flexibly and rapidly to new technological trends and on building bridges between academia and business. With its programmatic orientation towards R&D funding for creating innovation-friendly framework conditions, and researching and/or establishing coherent strategies between the academic, business and political spheres, the program corresponds to the core goals of the High-tech Strategy.

This article provides an overview of the contents, structure and governance of the program. It focuses on newly introduced funding instruments and their targeted adaption to the specific features of the R&D object innovative capability. Particular attention is paid in this to the importance of the program's learning and transfer capability for funding innovative capability in business and society and the contribution of the monitoring and meta-projects.

2 Program Governance and Cross-Linkage

The high demand for top level research and the successful and rapid conversion of research outcomes into innovative marketable products and services poses specific challenges for the shaping of research and development programs (R&D programs).

[1] Cf. in this regard [Wis09, SGT09].

A research program that deals with strengthening innovative capability is itself faced with the challenge of fulfilling its own requirements. The research program "Working – Learning – Developing Skills. Potential for Innovation in a Modern Working Environment" of the BMBF is progressing in an exemplary manner in this regard. Since 2007, the program has been funding new approaches to HR, organizational and skill development which ensure that working and learning are combined in a single process and help maintain work capability and employability. The program appears highly aware of its own challenges with a new program management structure which equally accommodates both own learning ability and a wide range of innovative elements that apply at all levels of research funding.

3 Innovative Capability and Learning Capability

In an increasingly complex and dynamic world, the conditions under which innovative capability thrives are often highly context-specific and mostly apply only for a limited time. From a funding-policy perspective, this demands that acute problems be identified and addressed in ways which are both precise and timely. To fulfill these requirements throughout the whole funding period of the program, the program was set up as a Learning Program. The program has, to a well-defined extent, been designed from the outset to be flexible, adaptable, short and capable of learning in order to respond to new challenges through timely readjustment of the funding-policy activities. This inherent learning ability is established through program governance with a new type of structure and innovative instruments, which can be used to feed improvement incentives back from the projects to the program in a targeted way.

3.1 Instruments of the Learning Program

The idea behind the Learning Program was already tested in the previous program of "Innovative Work Design – the Future of Work" and was adopted in the current program of "Working – Learning – Developing Skills. Potential for Innovation in a Modern Working Environment" from the start as an integral component in designing the program. The learning program allows for reflections at all levels of funding during the program running time. At the same time, learning loops are also called for, and these need to incorporate the reflections in order to ensure both further development of the content priorities and suitable funding instruments. The following instruments have been integrated in the program design as elements of these "open program structures" [fBuF07a] and will apply within the framework of research funding and program governance:

1. "Impact analyses and strategic audits aimed at the BMBF funding program as a whole (after around five years) that are used for overall analysis of the fund-

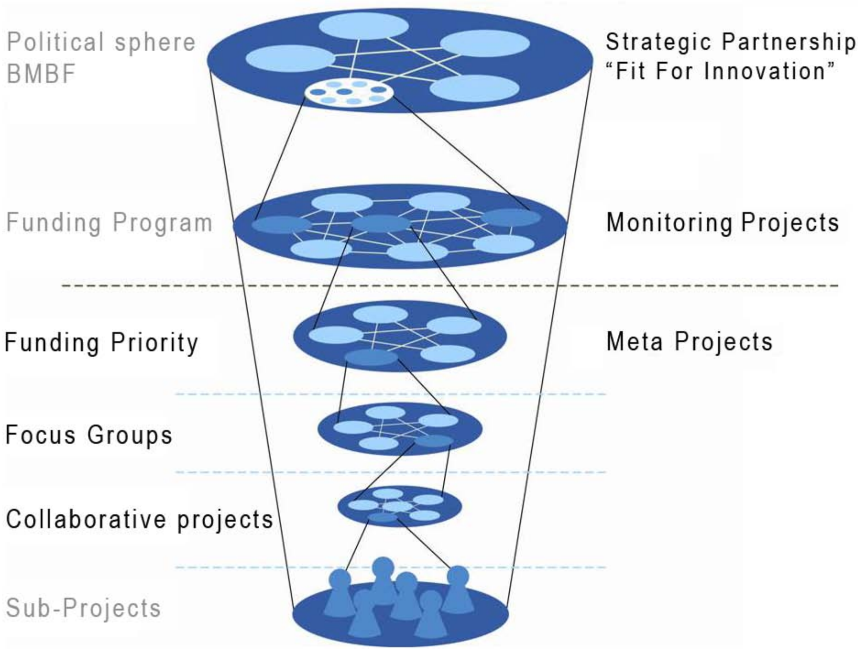

Fig. 1 Instruments and accompanying projects of the program "Working – Learning – Developing Skills. Potential for Innovation in a Modern Working Environment"

ing measures with regard to direct and indirect effects and the strategic further development of the program." ([fBuF07b]; Translated by author)

2. "Regular international monitoring processes that are used to integrate research activities into the international context and as a basis for critical discussions about the further development of the BMBF funding program [. . .]." ([fBuF07a]; Translated by author)
3. While evaluative elements and, if necessary, program monitoring instruments are to be found in this or a similar form in other R&D programs, what makes this program unique is its additional sophisticated program governance instruments. These were explicitly formulated as recommendations by an expert group during an evaluation prior to the current program and integrated from the outset during reformulation of the program [HJKS07].

There follows an outline of the functions of the following instruments (cf. Fig. 1):

- Funding priorities
- Focus groups
- Collaborative projects
- Meta-projects
- Monitoring projects and the
- Strategic Partnership "Fit for Innovation".

3.1.1 Funding Priorities

The first instruments to be considered are the funding priorities of the program. Funding priorities reflect professional fields of action initiated by notifications as well as currently established topic areas, in which research projects are being funded.

Up to now, three funding priorities have been addressed in the program: "Innovation Strategies beyond Traditional Management", "Balance of Flexibility and Stability in a Modern Working Environment" and – the latest priority, which is still in development since 2010 – "Innovative Capability in the Context of Demographic Change". A further funding priority, "Preventive Occupational Safety and Health", began in 2005 under the previous program, "Innovative Work Design – the Future of Work" and was continued under the new program until its successful conclusion in 2010.

The notifications of funding priorities were published at intervals of approximately one year apart. This procedure has the advantage of providing an on-going program evaluation, allowing the contents of the details given in the notifications to focus on whichever areas of enquiry are of major social concern at that time. Because the Project Management Agency in the German Aerospace Center (DLR), and the BMBF cooperate closely with representatives of the funding priorities, new research questions and action requirements can be addressed in good time and used to readjust existing funding priorities or orient new ones. In addition to this contribution to the learning ability of the program, the funding priority forms a thematic framework for cross-linkage and exchange between the projects, which is then further subdivided due to the wide areas covered by the funding priorities.

3.1.2 Focus Groups

A focus group is a thematically focused subgroup within a funding priority, in which several collaborative projects with closely related contents are combined. A focus group works on a voluntary basis and without any formal legal basis. The functions of focus groups include promoting academic exchange at a higher aggregation level, ensuring internal cross-linkage, increasing external impact, for example through joint publications, and developing recommendations for action and research. A focus group is composed of members of the projects selected through a funding notification. A further aim is to harness and integrate the experience of external experts [Sar10].

Due to the thematic proximity, expectations are placed on the focus group to carry out joint activities (for example conferences, publicity work), exchange of academic findings as well as early recognition of the latest developments in the field. In a lesson learned report, the project "Strategic Transfer in Occupational Safety and Health" (StArG) indicates the strengths of the focus group concept, which are primarily apparent in network formation. However, StArG does not conceal the questions that have emerged during implementation, such as questions of financial resources for focus group spokespersons or the challenges in coordinating (shared) goals [BHL11].

The focus group is viewed positively overall as an instrument for network formation (community building) by the Ministry, the responsible project management agency and also in individual feedback from projects. A clear added value is acknowledged in comparison to the traditional funding of individual projects, regarding transfer and synergy promotion.

3.1.3 Collaborative Projects

Collaborative projects between companies, research partners and intermediaries form a thematic nucleus within which multiple subprojects are combined and a research idea is formulated. Representing the collaboration, the collaboration coordinator submits the joint project outline in response to a notification. In case of a call for applications, a joint project description is agreed as the binding basis of the subsequent form of the project by the collaborative project and then submitted. Despite the professional agreement, which is regulated within the collaboration via a syndicated agreement, each subproject receives its own allocation in terms of licensing rights. This means that, on the one hand, the collaborative subject matter is protected, while on the other hand, however, individuality and confidentiality are guaranteed in funding matters.

3.1.4 Meta-Projects

As a further program governance instrument, the funding priorities are each accompanied by a meta-project and if necessary meta-studies which process cross-sectional themes. Meta-studies, according to the program's recommendations, should be assigned to individual funding priorities and shall integrate their results into the current priorities [fBuF07a]. All funding priorities are currently accompanied by meta-projects.

Meta-projects address inter-project issues within their funding priority and therefore assist the further development of the content of the whole R&D area. Through close dialogue with the focus groups and collaborative projects, they continuously collect and consolidate current project outcomes, so as to compare these with the targets of the program. A notification's areas of activity are thus linked and consistently combined to form an integrated overall picture. This allows, for example, stakeholders in research, HR planning, training institutions, chambers and social partners to receive the corresponding information on important trends, developments and discussions in order to take these into account in their activities. In this way, the meta-projects generate incentives for further development of the research program.

Among the funding priorities to date on prevention, innovation strategies and balance of flexibility and stability, meta-projects were set up entitled "Strategic Transfer in Occupational Safety and Health" (StArG), "Innovation Capability as

Fig. 2 Overview to the meta-projects of the program together with their running times and allocation to funding priorities

a Management Task, Synthesis, Transfer and Support of Research and Development Projects" (MANTRA) and "BALANCE". A new meta-project for the demographics funding priority will start in 2011. Owing to the running times of the funding priorities, the StArG project from the "Prevention" funding priority was the first to be completed (cf. Fig. 2). The Lessons Learned report refers the StArG Project, among other things, to the fact that the new instruments have resulted in new functions and therefore also new roles which not only need to be individually filled in a suitable way, but also need to interact with each other appropriately. It refers to the focus-group spokespersons, meta-project advisers for the focus groups and those responsible for the focus groups at the Project Management Agency in the German Aerospace Center (DLR) [BHL11].

3.1.5 Program-Supportive Projects: Monitoring Projects

Like the meta-projects, monitoring projects are tasked with bundling research results from all the funding priorities of the program process-supportively, reflecting them and thus identifying knowledge gaps and action requirements for program development which could not have been deduced from notifications alone. In this way, the monitoring projects fulfill a basic function within the framework of the Learning Program. The tasks of the monitoring projects also include observing international developments, comparing findings from programs in an international context and identifying and valuating national and international dilemmas and suitable solutions. Likewise, a network of experts extending beyond the national community is to be set up.

Within the BMBF program on “Working – Learning – Developing skills. Potential for Innovation in a Modern Working Environment”, the Centre for Learning and Knowledge Management/Information Management in Mechanical Engineering of RWTH Aachen University (IMA/ZLW) have been assigned the task of program-supportive “International Monitoring” (IMO). The IMO project procedure for fulfilling these stated tasks is shown below, with particular emphasis on the influence of transferability of R&D programs on the opportunities and limits for increasing innovative capability.

3.1.6 Program-Supportive Projects: Strategic Partnership

The Strategic Partnership “Fit for Innovation” is constituted as a knowledge, transfer and learning forum, which was established as program-supportive with a particular focus on the Practice target group. Within the forum, companies exchange views and are provided with academic support in finding suitable instruments with which innovations can be stimulated and necessary changes within the company can be initiated. At the same time, the Strategic Partnership provides companies with access to the outcomes of research and new methods of personnel, organizational and skill development. The Strategic Partnership is therefore important in setting a course to increase innovative dynamism within companies in a targeted way, support the development of innovative capability sustainably on a large scale and therewith promote a climate for innovation in Germany.

The members and key knowledge carriers of the Partnership are the representatives of companies, flanked by partners from academia and research. So as to focus on the varying needs and interests of the companies, the Partnership is divided into topic areas, to which interested companies can then attach themselves. One hundred companies are currently engaged in the “Fit for Innovation” Strategic Partnership in six topic-specific study groups. They engaged in the activities by sharing their experiences or by gaining effective recommendations for action based on the experiences of others. The key materials the study groups deal with are the experiences of companies and also instruments used in pilot trials in companies from the program “Working – Learning – Developing Skills. Potential for Innovation in a Modern Working Environment”. So as to make the experiences shared in the business to business dialogues in the study groups available to further companies in a targeted way, the Strategic Partnership employs both conventional and innovative means of transferring and disseminating knowledge.

The expectation placed on the Strategic Partnership is that the exchange of experiences among the companies and the dialogues with the partners from the research world, which provide direct access via the Partnership to innovative instruments and experiences of personnel and organizational development, will lead to a direct acceleration in the rate of innovation in these companies. A key role in this is played by the spokespeople of the Partnership, who are composed of senior company representatives of a well-known medium-sized company in Germany as well as the Director of a Fraunhofer Institute.

4 Innovative Capability and Transfer Capability

With the "High-tech Strategy for Germany" and its further development "High-tech Strategy 2020 for Germany", the German Federal Government has developed, set in motion and implemented a cross-disciplinary innovation concept [fBuF06, fBuF10]. Embedded within this are employment research and service research with their current funding programs. A central remit of these programs is to transfer academic findings to practical applications [fBuF07a]. The transfer of academic findings into operational personnel, organizational and skills development frequently encounters hurdles, for which additional program-supportive instruments are made available in the R&D program "Innovative Capability in a Modern Working Environment" research program.

4.1 The Transfer Mission of the IMO Project

To improve the transfer from science to science at an international level and from science into practice, the findings currently generated in the program for enhancing innovative capability by the IMO Project are collected, summarized and their transfer is then supported. This requires specific processing of the results for the target groups economy, science and politics. To validate the national results, identify research gaps and determine research requirements early on, these are reflected by IMO in the international context.

To perform these tasks, IMO uses an extensive portfolio of diverse monitoring instruments. The instruments used by IMO range from participation in funding-priority and focus-group events to expert interviews and running its own summer schools, innovation workshops and international conferences. Important instruments for establishing the learning capability of the program are the two expert panels: IMO coordinates a national and an international panel with members from science, politics and economy.

To respond in good time to the diverse challenges involved in funding innovative capability, program-complementary fields of action were identified by the national panel and worked on by expert teams. To this end, experts from the academic and practical spheres wrote expertises, trend studies and whitepapers in which current results and future research requirements for political action are formulated in detail.[2]

In their work, the experts of the IMO fields of action referred repeatedly to an almost paradoxical finding related to the funding of innovative capability, which had been mentioned in in-depth expert interviews [SBL10]: One of the results to be transferred in order to increase innovative capability states that result transfer itself needs to be reassessed and changed. Innovative and transfer capabilities are closely linked to one another; the ability to generate and adapt solutions through interactive

[2] The trend studies, expert reports and white papers worked on so far can be downloaded from the IMO Project homepage (www.internationalmonitoring.com).

knowledge generation, information selection and exchange of experiences is an important prerequisite for the innovative capability of companies [SBL10]. The thesis can be derived from this that, for any further development and enhancement of innovative capability in addition to intensive content-based research into inhibiting and promotional factors of innovative capability, awareness and targeted application of findings from company practice which are already available is essential.

The central program remit stated above – to transfer academic findings into practical applications and transform academically well-founded concepts into operational HR, organizational and skill development or suitable business models – cannot be implemented through a funding instrument which focuses exclusively on individual projects according to the experts. The funding program "Working – Learning – Developing Skills. Potential for Innovation in a Modern Working Environment" addresses these needs: as a center of academic research, Germany has a wide range of knowledge for strengthening innovative capability in combining measures of HR, organizational and skill development. The competence for disseminating and implementing this knowledge in the German economy is available and must be promoted. That is why the program represents a considerable advance over project funding. In the context of this program, basically only associations, that is to say consortia, are funded, in which practice and research work closely together from the initial research phase onwards. This ensures that transfer capability is already guaranteed within this consortium.

The OECD points out in its 2010 Report on innovation that in Germany basically too much time elapses from the development of the idea to the actual market launch (Time-to-Market Performance), meaning a fundamental need for change and improvement existing at this stage.

4.2 Underlying Problem Areas for Result Transfer in Projects

Within the framework of interviews with experts and national working groups, the following key problem areas and dilemmas in the area of application-focused research with innovations were identified by the experts questioned as confronting R&D programs in general:

- *Transfer after the end of funding*: In some, new largely concluded R&D programs, a transfer of findings from the research activity was down-streamed. This meant that consideration of how a transfer of the findings can be effected is also delayed into the concluding phase of a project. This contradicts the experience and clear recommendation of the experts for integrating successful transfer to the partners in practice directly into a project – the sooner, the better. In practice, it is certainly acknowledged that the conclusion of a research and development program for every project results in extensive concluding reports and a wealth of publications are available as research outcomes, the evaluation of which, however, can no longer be assured in the case of a downstreamed transfer.

- *Transferability of results*: A frequently addressed, but in the view of the experts too little analyzed, problem is the transferability of successful solutions – in view of how conducive the work is to learning and skill-building – but also the learning of organizations. Research gaps with urgent needs for action exist in this area, according to the recommendation of the circle of experts on organizational learning and on successful transfer concepts, to enable conditions to be created which promote learning or which can be transferred to other organizations [Har11].
- *Resources for transfer work*: In R&D programs, in addition to the actual funding, enhanced transfer funding is also increasingly being required. In view of this, the circle of experts urgently advises that planning includes a framework for adequate resources of time and finances for research, academic support and transfer in research and design projects and is considered on the part of the funding providers [SBL10].
- *Target-group oriented processing*: The academic interviews identified a transfer dilemma lying in the fact that preparing a target group-oriented processing of outcomes for practical application calls for linguistic simplification and catchy representation, which is frequently associated with trivialization in of the area of academic communications. At the same time, linguistic processing requires additional, more journalistic competence. The high level of academic professionalism required for scientific study and the right to carry out research thus conflicted with the additional, but simultaneously also just as professionally required transfer in a target-group oriented manner. As both the academic representation and the transfer of the academic outcomes in the language and modes of thinking of the companies are crucial for the success of a project, it is proposed to include the target companies as well as additional company-related institutions (e.g. associations, transfer agencies) in the process of knowledge generation from the outset [SBL10].
- *"Information overload" on the company side*: For companies, the central dilemma of transfer lies in the relationship between the quantity of findings offered and the capacity for processing and applying this information. Companies are "drowning" in a flood of information in the form of newsletters, brochures, blogs etc. As regards transfer, this means that, in addition to providing information, intermediaries also have responsibility to select information appropriately [SBL10].

4.3 A New Transfer Understanding

To summarize, the following can be concluded from the IMO results to date of both the national panel and the in-depth expert interviews: Transfer requires, both from the perspective of academic as well as the economic stakeholders, focused governance and programmatic imbedding. The knowledge and service society produces to a degree more complex and higher requirements for transfer than in an industrial society – a new understanding of transfer is needed. Traditional views, according to which science is ready to provide the solution to any problem and that this then only needs to be applied are obsolete. More modern and effective transfer can only be achieved through active integration and communication of all participants on the academic and practical sides. New interactive and communicative models for shared generation of knowledge and solutions are called for. The "Working – Learning – Developing Skills. Potential for Innovation in a Modern Working Environment" R&D program for this reason tests new approaches by basically funding collaborative projects in close cooperation between academia and practice and applying different instruments for transfer and cooperation in networks. In addition, as program-supportive measures, both IMO Project and "Fit for Innovation" represent a new understanding of transfer.

4.4 The IMO "Transfer" Field of Action and Its Four Cross-Sectional Research Tasks

In view of the complexity and urgency of the transfer problem as outlined above, the IMO project has developed in close collaboration with the BMBF a new field of action to improve the transferability of R&D programs in the field of innovative capability. The project aims to provide incentives for developing and establishing a new transfer understanding. The concrete goal of the field of action is to provide action recommendations for implementing this transfer understanding within current and future program funding.

Overall, the transfer understanding should clearly distance itself from technicistic sender-receiver models and the knowledge gain should be based on partnership-oriented and continuous interaction of all relevant transfer partners. Transfer must not be seen as a modular work package that is only tackled once the academic results are completed and consists solely of the printing of academic publications. Promoting transfer means more than increasing the circulation. Promoting transfer means increasing individual and organizational transfer skills and optimizing the transferred knowledge itself, taking into account the needs of the target group and integrating this target group right at the start of knowledge production [HL10].

The success of a research and development program in strengthening innovative capability must not be judged solely on the basis of the quality of the content of the solutions developed, but must also in future be measured against the subsequent diffusion of this newly acquired knowledge into corporate practice. Not just the production of knowledge, but also its transfer, is a task that researchers must (help to) shape in order to increase the sustainability of the funding. Researchers' understanding of their roles and tasks must be expanded so that it goes beyond the generation of new knowledge to actively helping to ensure its application, and the users themselves must be integrated into this process. Researchers as well as practitioners must be more effectively enabled to transfer structuring solutions and for the establishment and strengthening of innovative capability. The goal of transfer is changing from knowledge production to enabling, in the course of which the trans-

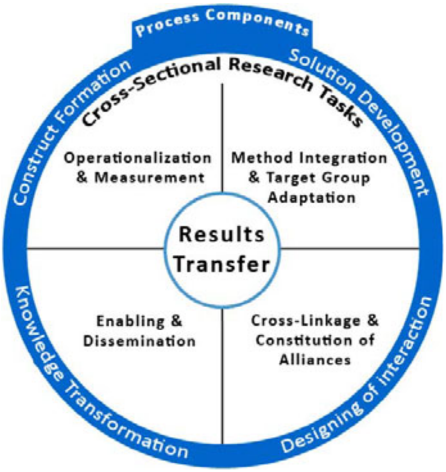

Fig. 3 Cross-sectional research tasks for promoting the transfer capability of R&D programs

fer partner is not just informed about the action requirements but also enabled to act.

> In principle, SMEs must be better enabled to increase innovation transfer in the use of modern technologies and the implementation of academic findings – and also particularly of work structuring and management. Innovative solutions must be transferred quicker and more effectively on a more widespread and practice-oriented basis. Different, more effective forms of transfer must be found for this. ([Bra10]; Translated by author)

As part of monitoring activities, the IMO Project recommends four cross-sectional research tasks[3] as approaches for sustainably establishing successful transfer in the "Working – Learning – Developing skills. Potential for Innovation in a Modern Working Environment" as well as the following funding program for enhancing innovative capability:

- Operationalization and Measurement
- Method integration and Target Group Adaptation
- Cross-Linkage and Constitution of Alliances and
- Enabling und Dissemination.

The cross-sectional research tasks represent inter-thematic activities to be allowed for in the transfer design of a funding program and which increase the probability of transfer success by helping to implement fundamental process components of the transfer. The cross-sectional research tasks are explained individually below together with associated research questions.

[3] The four cross-sectional research tasks are to be seen as routing differences, delimiting the scope of the stated transfer term as it appears to be target-aimed in the current situation. In this process, the question remains as to how strong the overlaps are between these groups of topics, for how long precisely these four cross-sectional research tasks will retain their validity, or whether they will need to be focused or supplemented in the course of the research.

4.4.1 Operationalization and Measurement

Operationalization and Measurement aims at the formation, delimitation and measurement of "innovative capability" and associated factors. The capacity of individuals, organizations, networks and societies to create innovation as the key to competitiveness depends to a crucial extent on the underlying understanding of the concept and its aim. A selection of suitable strategies, methods and measures is based on the most objective measurements possible, which presuppose comparability and sufficiently similar operationalization processes. Ultimately, the question of positive and negative influencing factors of innovative capability and therefore the question of the "innovative capability" concept in general depends on reliable and valid operationalization and measurement methods. What is frequently lacking is not data availability, but rather the fact that available methods and data are often unsatisfactory in mapping the complex investigation phenomena, not generally applicable, or not widely accepted. From a pragmatic perspective, there is also the fact that implementation of the findings in the company usually still requires proof of concept by means of quantitative data.

Examples of research questions for this cross-sectional task are as follows:

- What aspects must be taken into account for the operationalization of a holistic "innovative capability"?
- Alongside quantitative indicators, how can crucial qualitative and subjective aspects also be integrated into the measurement of soft factors?
- How can the comparability of the constructs be preserved despite individual operationalization methods?

4.4.2 Method Integration and Target-Group Adaption

Method integration and target-group adaptation comprises the identification of necessary steps during the development of customized solutions. The technical specifications and also attempts of interdisciplinarity have led to a heterogeneous variety of methods in the sciences and afford the opportunity of optimization. A lack of dissemination of academic insights, procedures and approaches to solving problems in economic practice cannot just be the result of limited application opportunities, but could also be considerably increased through more intensively conducted interdisciplinarity and integration of new methods, e.g. directly during its creation process. However, the aim and challenge must not be the conglomeration of one-size-fits-all concepts, but the joint development of flexible methods that can be adapted to the specific needs of the companies (to some extent even by the companies themselves) [fBuF07a].

Examples of research questions for this cross-sectional task are as follows:

- How can methods be constructed in an interdisciplinary manner?
- How can methods be adapted to the individual conditions and requirements of organizations?
- How can the expert knowledge of the practitioners be made usable for method integration?

4.4.3 Cross-Linkage and Constitution of Alliances

Cross-linkage and constitution of alliances deals with the processes and technical infrastructure for structuring the virtual and real interaction between relevant stakeholders. To prepare actual implementation of (integrated) methods optimally not only requires the theoretical combining of content, but also the relevant stakeholders and institutions from research and practice must be brought together in a practical sense. Only through cross-linkage and intensive exchange can the theoretical content of research be adapted to the practical needs of companies and made usable by them [HL10]. Further to the required merging of academia and practice, internal practice and research cross-linkages are also highly significant [Bul06].
Examples of research questions for this cross-sectional task are as follows:

- What cross-linkage structures and technical infrastructure can be used to establish effective, lasting and flexible cooperations between research and practice?
- Which relevant stakeholders must be integrated in the transfer process at what time?
- How can motivation and benefits be increased for all transfer partners?

4.4.4 Enabling and Dissemination

Enabling and dissemination explains processes of knowledge transformation for the assimilation, dissemination and application of results. The basic problem of enabling is the impossibility of simply copying knowledge. Only explicit knowledge can be directly transmitted, but only implicit knowledge can enable actions being taken [Pol85]. The challenge therefore lies in the communicative formation of transformation processes between explicit and implicit knowledge. The application of explicit research knowledge requires the skill to contextualize, i.e. knowledge to be applied to new practical problems. From the manifold research outcomes from various academic subareas, the way into economic practice could be opened up for many through this. It had been hoped that the evaluation, dynamic in its own right, of outstanding theoretical results and prototypically successful practical implementations within the framework of collaborative projects would be provided with considerable momentum [LH08]. From the perspective of the project, it is therefore recommended that the idea of the transfer is to be supplemented or even be replaced by the active moment of practical implementation and the idea of enabling [TSHJ10].
Research questions for this cross-sectional task are as follows:

- How can researchers and practitioners be enabled and motivated to undertake mutual and target-group-oriented knowledge requirements and provision?
- How can translation or commercialization processes be used to reduce the knowledge gap between research and practice?
- How can models of knowledge coproduction (“Action Learning”, “Work Based Learning” etc.) be made time-efficient and comprehensive?

5 Summary

The promotion of innovative capability is a key lever for securing and developing the economic ranking and research status of Germany amongst its international competitors. This was acknowledged with the High Tech Strategy of the Federal Government and, among other measures, translated and applied into targeted funding measures in the "Working – Learning – Developing Skills. Potential for Innovation in a Modern Working Environment" R & D program of the BMBF. The "innovative capability" object of research indicates complex prerequisites for the creation and forms of innovations which require flexible and specific funding instruments. The BMBF is responding to these requirements with open program structures that create inherent learning ability in order to address the changing challenges efficiently and in good time. In addition to the learning capability of the program, the transfer capability of the program represents a key skill, with which innovative capability is supported. The IMO Monitoring Project handles this topic with an field of action of its own, in which a new transfer understanding is worked out for the transfer of results from R&D programs in the area of innovative capability, while the "Strategic Partnership" represents what has up to now been a very successful attempt to promote and experience transfer with partners in practice within the network.

While IMO performs its activities at the level of the whole program, the meta-projects of the program operate at the level of the funding priorities. Its current findings regarding internal and external funding-priority transfer activities represent a large proportion of the academic basis for distilling the four cross-sectional research tasks proposed by IMO to increase transferability. Because of their closeness to the project participants, the meta-projects are particularly significant for establishing and increasing transferability and ultimately innovative capability. Independently of the different thematic orientations of the meta-projects resulting from the relevant funding priorities, they are all jointly tasked with the bundling and processing of results.

In the following three articles, the current meta-projects StArG, MANTRA and BALANCE provide a brief overview of the findings to date of their accompanying funding priority. StArG outlines the potential of Preventive Occupational Safety and Health to improve working conditions and boost the motivation and performance of employees as a prerequisite for the innovative capability and competitiveness of companies. The MANTRA project deals with work organization processes and demonstrates that innovation strategies converge at right angles to thematic priorities in three dimensions: nonlinearity, exceeding organization boundaries and subjectification. The latest BALANCE meta-project focuses on the use of social software in project work for the identification of network partners, the organization of networks and the archiving and dissemination of project content beyond institutional, disciplinary and physical boundaries.

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A Conceptual Agent-Based Planning Algorithm for the Production of Carbon Fiber Reinforced Plastic Aircrafts by Using Mobile Production Units

Hamido Hourani, Philipp Wolters, Eckart Hauck, Annika Raatz, Sabina Jeschke

Abstract In order to adapt to new modifications of a product, a new production line and competences should be developed. Enhancing this adaptability feature is the target of the presented conceptual approach. This target is achieved by constructing a product, which is fixed at its place, by heterogeneous mobile production units. In this paper, the product is an aircraft which is made of carbon fiber reinforced plastic. Having two types of agents (i.e. planning agents and representative agents), the conceptual approach supports flexibility and parallelism too. The planning agents depend on their general knowledge on the construction progress to provide an abstract plan. The representative agents, which represent the physical production units, depend on their local surrounding environment to draw a concrete plan from the provided abstract plan. Defining the roles of both types of agents are also within the scope of this paper.

Key words: Assembly Automation, Composite Material Aircraft, Multi-Agent System, Planning

1 Introduction

Due to the competition between different providers of a product, a rapid development process is needed to adapt to changing requirements. Therefore, the product life cycle is shortened [SHS+08]. Consequently, changes to the production lines are required and the competence of the development team (i.e. human operators) must be adapted to the new production lines.

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To avoid the cost of redesigning the production lines, a product can be constructed and assembled at the same place. However, this production approach reduces the throughput of the product, due to overlapping of the workspaces which each operator works on.

This paper introduces a conceptual approach to achieve the parallelism feature and the adaptation of changes at the same time. In this conceptual approach, a team of heterogeneous production units (i.e. robots) will be used to construct and assemble an aircraft. The fuselage of the aircraft is stationary while the production units are moving around and inside the fuselage to assemble the required pieces of the aircraft.

From this scenario we focus on the conceptual planning algorithm to construct an aircraft by a group of mobile heterogeneous production units. In addition to plan and schedule the activities of the production units, this planning algorithm supports the parallelism, adaptability and flexibility features. By parallelism feature we mean: The production units, which have different assigned tasks, are able to carry out their tasks in parallel even when their workspaces are overlapped. And by the adaptability feature we mean: Adding new customizations of an aircraft or changing its design is adapted by the production units. However, these changes are not applied to the currently running product. By the flexibility feature we mean: A centralized system supports each production unit with an abstract plan. Customizing this plan and generating a concrete plan by depending on the current situation of the workspace is achieved independently by each production unit. However, the abstract plan is used as a frame around the generated concrete plan.

This paper is organized as follows: The application scenario is elaborated in Sect. 1.1. The related literature is presented in Sect. 1.2. The requirements, which the planning algorithm must address, are presented in Sect. 2. The architecture of the agent-based system is elaborated in the first part of this paper [DLJRed] but the main features are outlined in Sect. 3.1. Section 3.2 is dedicated to the conceptual planning algorithm. The scientific contributions of this paper are presented in Sect. 3.3 and Sect. 3.4 gives an outlook for future work. The conclusion is presented in Sect. 4.

1.1 Application Scenario

By depending on a new type of Carbon Fiber Reinforced Plastic (CFRP) technology, the fuselage of the aircraft will be designed as a geodetic lattice frame [VBR01]. On this geodetic frame, small plates have to be fixed.

To achieve adaptability and parallelization in performing tasks, using small mobile production units is proposed to fix these plates and to assemble other pieces of the aircraft. However, the concurrency, the dependency among tasks and the overlapping of the workplaces are challenges which the group of mobile production units have to face.

In addition to the production units, several logistic units are involved. These units are responsible for providing the production units with the required tools and materials.

Apart from production and logistic units, several sensors are spread inside and outside the geodetic lattice frame. The task of these sensors is to update the central units about the progress of the tasks and the quality of each accomplished task. After each task, a quality step must be performed. In this system, if a task has not achieved the required quality, a recovery process is established.

Each production unit, logistic unit, and sensor is represented by an agent in a centralized system. This representation reduces the complexity of the system and enhances its scalability [WDM07]. Each agent represents its corresponding external unit. In addition to these representative agents, planning agents are added to the system. These planning agents have the responsibility to schedule the tasks. The representative agents, in turn, have the responsibility to carry out these tasks.

The Market-Based Approach will be followed inside this system to allocate the tasks to the representative agents. In this approach, a task is announced by a specialized planning agent and the representative agents start bidding to seize it. Each representative agent specifies its price for the announced task.

This paper is based on the coordination between the institute of Information Management in Mechanical Engineering (RWTH Aachen) and the institute of Machine Tools and Production Technology (TU Braunschweig University). The scope of this paper is the conceptual planning algorithm. The Technological Requirements and Software Infrastructure of this planning algorithm are elaborated in [DLJRed].

1.2 Related Literature

Automated planning strategies are classified into two types: Off-line Planning and On-line Planning [Nau09]. Off-line Planning takes place a priori and does not adapt to changes. On-line Planning, in turn, means adapting to changes and replanning based on them.

Since aircraft manufacturing techniques are precisely described and its assembly processes follow strict sequences [SBMB09], it fits under the Off-line Planning strategy. However, due to complexity of manufacturing an aircraft and the dependencies among the involved components, several defects are possible to appear during the manufacturing process [JKI$^+$09]. Thus, correction steps are introduced to reduce the effect of these defects. In order to meet these corrections, a switching from an Off-line Planning to On-line Planning is required.

Multi agent systems can achieve considerable progress in the planning and control of complex commodity flows, compared to conventional flow concepts [TNNSIT10]. Furthermore, these agent systems have been introduced into the state of the art of industrial technology [WDM07]. For the production, there are similar approaches which especially aim at flexibilisation of the material flow management, rapid start-up, or best possible reconfigurability [TNNSIT10, VROM09].

A planner has the responsibility to generate a plan which consists of a set of actions. Allocating resources to these actions and specifying the suitable time for executing them is the responsibility of a scheduler [Nau09]. Designing a scheduling system for automated assembly in a non-deterministic environment was addressed by the institute of Information Management in Mechanical Engineering (RWTH Aachen) in a project within the scope of the Cluster of Excellence "Integrative Production Technology for High-Wage Countries". In this project, a scheduler for an automated assembly process was designed to adapt to random working piece conveyance, deduced solely from the current situation and a Computer Aided Design (CAD) description of the final product [HESJ10, HGH09].

The problem with task allocation is the process of assigning a set of tasks to a team of agents. Two main approaches address this problem [Par08]; the Behavior-Based Approach and the Market-Based Approach. In the Behavior-Based Approach each robot tries to estimate its colleagues' capabilities (i.e. sensors, power) and its state (i.e. busy, free). Based on that, each robot can determine which robot should do which task. Several algorithms belong to this category such as ALLIANCE [Par94] and Broadcast of Local Eligibility for Multi Target Observation [WM00]. In this approach there is no explicit communication among robots regarding task assignments. In addition, it depends on distributed coordination [Par08].

The Market-Based Approach, on the other hand, depends on explicit communication among robots regarding task assignments. It is based on the market theory and has been applied to a team of robots [DZKS06]. To determine which robot should do what, each robot has to attend an auction to get a task. To bid in this auction, a robot has to estimate its capabilities and availability in addition to the cost of doing this task. Then the robot sends the result to the auctioneer. The robot's capabilities, availability and cost together are called Robot Utility. Cost estimation depends on several factors such as the time which is needed to accomplish the task and the distance between the bidder robot and the task location [DZKS06].

In this proposed algorithm, the Market-Based Approach is used between the planning agents and the representative agents to announce and allocate the tasks. The Behaviour-Based Approach, on the other hand, is used among the representative agents to coordinate their activities when they are working at the same workspace.

2 Requirements

Several requirements must be addressed by the proposed planning algorithm in order to apply it to the production of the aircraft. This section presents the requirements which directly affect the planning algorithm, namely: task requirements and Agent requirements. Other requirements are discussed in [DLJRed].

Considering the tasks, most of the tasks of assembling aircrafts are known to the system in advance. But, these procedures must be represented in a language which can be interpreted by agents. Furthermore, dependencies among tasks and shared resources must be maintained. Performing two or more independent tasks at the same time issues the risk of collisions of physical units. This situation appears when the workspaces of these tasks overlap. Each task should have an associated documentation which shows the prerequisites to achieve it and the expected outcome as well as the expected quality. In case a task, which is accomplished by an agent, does not meet the required quality, a task recovery must be added to the list of tasks.

Apart from the requirements of tasks, agents on the other hands have their requirements. The dependencies among agents, material flows, and the selection of a suitable solution for integrating their activities must be considered by a planning algorithm. The skills of each agent play a role within the negotiation sessions (i.e. auction) to seize a task. If an individual agent does not meet the required skill to carry out the available task, an ad hoc group of agents will be formed. The gathered skills of this group should satisfy the available task. Since it is important to utilize all agents during the production process, each agent or group of agents has to participate in these negotiation sessions. This utilization approach assures that every agent is utilized. On the other hand, held tasks should be avoided. A held task is a task which is reserved by an agent, while this agent is busy with another task.

3 A Concept for Agent-Based Planning and Control of the Assembly of Carbon Fiber Reinforced Aircrafts

This section presents the conceptual architecture of the agent-based planning and control system. Inside this architecture, our conceptual planning algorithm works.

3.1 The Proposed Architecture

The core of this architecture is motivated by a market placed center concept. This core has interfaces with two main sides. The first being the task side and the second being the physical hardware side (e.g. the mobile production units). Figure 1 depicts this architecture.

To exemplify this architecture, let us suppose a new design of an aircraft is modelled using CAD. This model is the input of the system. The system interprets it by using certain transformation steps. This interpretation is decomposed into several simple tasks which can be accomplished by robots. These simple tasks are stored in the task database. Figure 2 depicts this decomposition.

The task database consist of two components: The first is the list of tasks and the second is the documentation of these tasks. In the documentation, the accomplished tasks and their associated quality management results are recorded. Once the task database is ready, the work inside the market place center starts.

The actors inside the market place center are agents. These agents are either planning agents or representative agents of physical entities. Tasks are allocated to the representative agents through the planning agents. The elaboration of this procedure is the scope of Sect. 3.2.

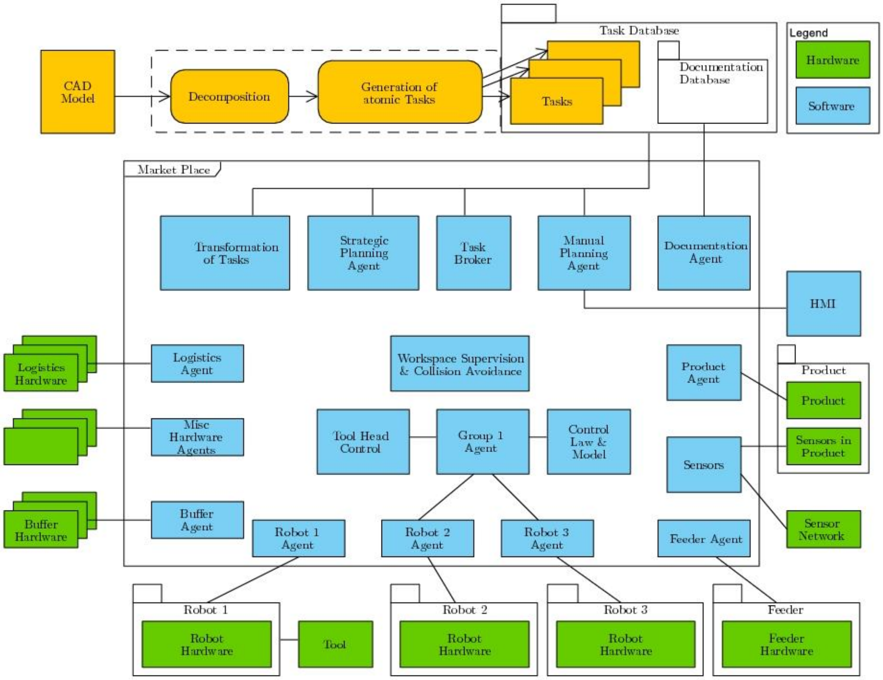

Fig. 1 The framework of the new concept for the production of CFRP aircrafts [DLJRed]

Each representative agent has a direct communication channel with its corresponding physical entity. Using this channel, both of them update each other continuously about their activities. This tight communication allows agents to bid for tasks on behalf of their corresponding physical entity. Entities, on the other hand, perform these tasks and update their corresponding agents with their progress. These entities could be production units, feeders, logistic units or sensors.

On the right side of Fig. 1, a HMI component (Human Machine Interface) is placed, allowing a human to intervene in the system to solve some conflicted situations. For instance, a task does not meet the quality requirements and the recovery process cannot resolve this situation. In this case, a human operator is needed to resolve it. The detailed description of this architecture is presented in [DLJRed].

3.2 The Conceptual Planning Algorithm

The input of the market place is a set of simple tasks which are stored in the task database. Dependencies among these tasks are maintained and represented in a dependancy graph.

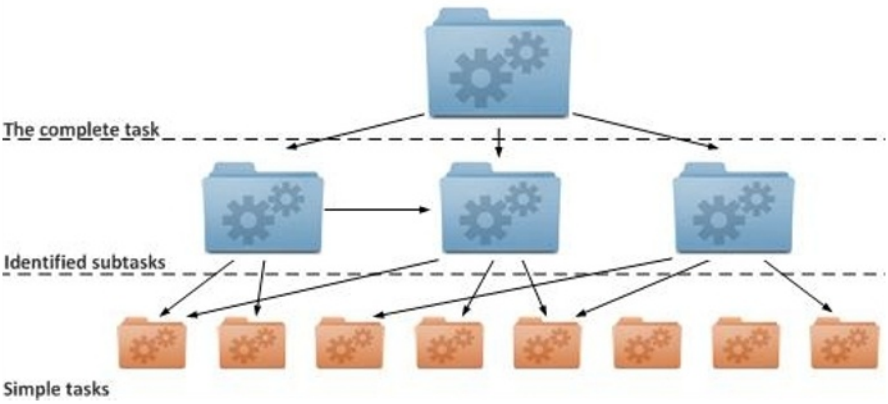

Fig. 2 Tasks decomposition

The planning agents are responsible for fetching the appropriate set of tasks from the task database. By the appropriate set we mean: The set of tasks which could be performed at the current status of the constructed aircraft. For instance, while the workspace at the end of the aircraft fuselage is crowded, the planning algorithm fetches a task which is performed on another workspace (e.g. on a wing). Once a task is fetched, the market based approach is carried out. In this approach, the task is announced to the representative agents.

Either a single representative agent or a group of agents bids its price to acquire the fetched task. The price depends on the agent's market unity. An agent market unity, among other things, consists of the agent's skills, its current distance from the task workplace, its status (e.g. busy, idle), and the number of its reserved tasks. If an agent wins the bidding, it is responsible for carrying out the task within the time and resources constraints, while maintaining the required quality of the task.

In addition to the planning and representative agents, the planning algorithm has a documentation agent. This special agent has the task to record the agents' performance and their allocated tasks. Besides, it has a direct communication channel to the documentation database to update it with the accomplished tasks.

3.2.1 The Planning Agents

The planning agents are depicted on the upper side of the market-place (Fig. 1). To exemplify these agents, we explain them by tracking a task which is passed through these agents. This task is to fix a plate in a specific place inside the aircraft fuselage.

The simple tasks are stored in the task database and they are the inputs of the market place center. Despite the fact that these tasks are simple, they need further analysis and transformation to describe how a task should be performed on a higher level. An agent transfers the task of fixing a plate into a set of instructions, such as through which entries of the fuselage can a representative agent use, to reach its target workspace. In this workspace, the representative agent has to fix the plate.

Due to its global knowledge about the progress of the construction and the crowded workspaces, the agent can control this scenario. The transformation step is done by the transformation agent (see Fig. 1, upper left corner of the market place).

Once a task is transferred by the transformation agent, the task broker agent begins the auction session for this task. The task transformation instructions are attached with the task. Thus, each representative agent can specify its suitable price. After a timer is expired, the broker agent announces the winner of the task.

Once the winner representative agent accomplishes the task by fixing the plate on the right place, a quality assurance process is issued. This process is needed to maintain the required quality of the accomplished task. For instance, if the plate is fixed and the gap between the plate and lattice is within the allowed range.

If the quality test shows that the task is accomplished successfully, the transformation agent fetches another task which depends on accomplishing the plate fixing task; for instance, to cover the fixed plate with another layer.

The previous mentioned workflow is termed as Off-line Planning because the simple tasks in the task database can be fetched in their usual sequence. This sequence is based on the dependencies among tasks. However, if the quality of an accomplished task does not meet the requirements, e.g. because the gap between the plate and the geodetic lattice exceeds the allowed range, an On-line Planning workflow takes place.

Besides cooperating with the transformation agent, the strategic planning agent takes the responsibility of solving this situation. Either it solves the situation by recovering the incomplete task or by ordering a task to remove the plate and rescheduling it as a new task.

3.2.2 The Representative Agents

The representative agents are depicted on the lower side of the market-place in Fig. 1. Each agent of this set represents its corresponding external unit such as a production unit. The agent exchanges the data with a software application which runs inside the external unit.

Once a broker agent puts up a task for auction, the representative agents start publishing their utilities to participate in the auction. Agents can either participate in the auction individually or as a team of agents.

The winning agent or agent group defines the concrete plan for performing the task. For instance, in which way the production units can move the plate through the gap, which is specified by the transformation agent, without affecting other agents' work. This concrete plan includes the coordination with the other units such as logistic units or feeder units. And it includes the required coordination to avoid collisions with other production units on the same workspace.

The concrete plan, which each representative agent derives, depends on the local situation of each agent. Therefore, it is not part of the responsibility of the planning agents which work on a higher planning level.

This approach makes the complete system a hybrid system. The high level planning follows a centralized approach and is done by the planning agents. The concrete planning, on the other hand, follows a distributed approach and is performed by the representative agents.

3.3 The Scientific Contributions

The scientific contributions of this paper are the following:

3.3.1 Adaptability and Flexibility

These features are achieved in the production line by depending on mobile production units and a stationary aircraft fuselage. These production units can directly adapt to customization of the product, once the CAD model is provided to the system. To provide the system with flexibility, two levels of planning are supported; namely: High Level Planning and Low Level Planning. High level planning is based on a centralized system and the transformation agent has the responsibility to carry out this level of planning. The transformation agent depends on its global knowledge about the construction progress of the aircraft. Based on this knowledge, it produces an abstract plan for each task. Low level planning, in turn, is based on a distributed system and the representative agents have the responsibility to carry it out. The representative agents depend on their local situations to derive a concrete plan from the provided abstract plan.

3.3.2 Parallelism and Workspace Overlapping

Since the constructed product is stationary, overlapping of workspaces is highly probable. Consequently, independent tasks with overlapped workspaces cannot be performed in parallel. In this situation, the parallelism feature is achieved by depending on the two levels of planning. Based on its global knowledge, the transformation agent supports the representative agents with recommendations to facilitate the transportation of the required materials to the target workspace. The representative agents, in turn, depend on their local environment to notice the current activities of their neighbour colleagues. Thus, they can coordinate with them directly to synchronize their activities on the shared part of the workspace, when needed.

3.4 Outlook

The current conceptual system is designed as a centralized system. This concept will be extended to support a distributed system approach on a higher level. This feature will increase the scalability of the system; thus, the number of representative agents could be extended further. Yet, the representative agents should always deal with this distributed system as a single coherent system. This means a transparency layer must be considered in the future work. This layer has the important role to give all agents the same chance of winning an auction in real time, thus they are virtually attending the same auction session.

Participating in an auction as a group of agents requires awareness of the skills of the other agents. Furthermore, agents have to distribute the transformed task among them to carry it out. This topic and the cognitive skills of agents will be addressed in the future work.

4 Conclusion

Due to fast changes of requirements, the product life-time is short. Thus, a new product line and competences should be developed to adapt to these changes. This paper presents a new conceptual approach to address, among other things, this adaptation challenge. In addition to this adaptability feature, the flexibility and parallelism features are supported by this approach. These features are maintained by heterogeneous mobile production units while they are carrying out their tasks on a stationary fuselage of an aircraft. These units are represented inside a centralized system by so-called representative agents. These agents have the responsibility to acquire tasks. Defining these tasks and announcing them is carried out by another group of agents, the planning agents. Moreover, the planning agents have the responsibility to provide the representative agents with recommendations for carrying out their tasks. The planning agents have this responsibility because they have a global knowledge about the progress of the constructed aircraft. Each representative agent, in turn, draws its concrete plan independently, based on its local environment. These two levels of planning are important to achieve the flexibility and the parallelism features. In order to meet the required quality, each accomplished task is followed by a quality assurance step. If an accomplished task does not meet the required quality, the startegic planning agent initiates On-line Planning to recover the previous situation.

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A Marsupial Relationship in Robotics

A Survey

Hamido Hourani, Philipp Wolters, Eckart Hauck, Sabina Jeschke

Abstract The diversity of tasks and work locations shows the need for heterogeneity among robot team members, where each group of robots is designed to fulfil specific tasks and to work efficiently in particular locations. To facilitate the missions of these specific task robots, logistic services have to be provided. A so called "marsupial relationship" – referring to the biological relationship between marsupial animals such as Kangaroos – can be one of these logistic services. This paper organizes and discusses the state of the art of this field. Besides, a precise definition of the marsupial relationship, which distinguishes it from other physical relationships in robotics, is presented. Moreover, a new organization and a detailed description of the marsupial members and their roles are given in this paper.

Key words: Biological Inspired Robot, Marsupial Robot, Physical Cooperative, Multi-Agent

1 Introduction

In comparison to a single robot, a team of robots has several advantages such as robustness, faster accomplishment of tasks and higher quality of the result. Furthermore, some tasks can only be accomplished by a team of robots because of the character and the complexity of the tasks [Par08].

Dudek's taxonomy for multi robots [DJMW96] classified teams of robots into three categories:

1. Identical composition COMP-IDENT (i.e. same software and hardware)
2. Homogeneous composition COMP-HOM (i.e. same hardware)
3. Heterogeneous composition COMP-HET (i.e. different software and hardware).

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This paper focuses on heterogeneous robot teams.

Amongst the heterogeneous team members, each sub-group of robots is designed to efficiently carry out a specific group of tasks. The work domain of robots at the task site is limited, if the design of these robots complies with the characteristics of the task limits. This design restriction impacts their performance negatively when they are performing missions which are unrelated to their specific tasks. For instance, if the design of the robots is optimized for an underground environment but they would have to cross an open outdoor area to reach it.

Because time is a crucial factor in several applications, especially in rescue missions [MTN+08], a deployment service for the specific task robots (i.e. underground rescue robots) either near or inside their target location should be provided. This is achieved by providing a carrier robot for these robots. In this paper the carrier robot is called Container Robot while the carried robot team members, are called Passenger Robots. The Container is able to traverse difficult terrain, which the Passenger Robots cannot traverse easily without consuming their resources. Besides, the Container delivers them to their work locations faster and safer. Following this approach, the robots benefit from their heterogeneity by using the strengths of each team member and by overcoming their limitations [KDP09].

This kind of physical relationship between robots is termed by Murphy et al. [MAB+99] as the marsupial-like relationship, analogue to the relationship between marsupial animals such as Kangaroos. Extended to the field of robotics, both the Container Robot and the Passenger Robots provide services to each other. For instance, while providing transportation to its Passenger Robots, the Container uses their sensors as extra mobile (non-attached) sensors [MAB+99].

A marsupial relationship in robotics comes into place in different fields of application which are underwater [ZCWT08], underground [ZLLZ08], ground [AMR96], aerial [SMV01] and space [SHK+05].

Within this paper, the state of the art of different marsupial relationships in robotics will be presented and discussed. Moreover, a precise definition of the relationship and detailed descriptions of the marsupial members and their roles will be given. We believe that this paper will play a key role towards accelerating the research progress in this field.

The paper is structured as follows: Section 2 elaborates the characteristics of the marsupial relationship and defines it precisely. The roles of the marsupial members are discussed in Sect. 3. Section 4 is devoted to the different applications of marsupial teams. In Sect. 5, Summary and Open issues complete this paper.

2 The Marsupial Relationship and its Definition

The marsupial relationship is a relatively new topic in robotics. Within this section, two research works are discussed to show the specific characteristics of the marsupial relationship and distinguish it from other physical relationships in robotics.

The first research work is the work of Hirose et al. [HSF94]. They used a team of homogeneous robots where each member of the team carries out its tasks independently. In spite of this fact, they need to cooperate in some situations, such as crossing a cliff that a robot alone cannot cross. In order to do so, each robot carries one of its colleagues to build a connected chain. The carrying process is realized by equipping each robot with an arm and a knob. The arm is fixed on the front of the robot and the knob on its rear. Each robot holds the knob of its direct front robot to form that robot chain.

The second research work we discuss is the work of Anderson et al. [AMR96]. They used a team of two heterogeneous robots; a small-sized robot (the Reduced Access Characterization Robot (RACS)) and a large-sized robot (the Mobile Automated Characterization Robot (MACS)). Both robots have the mission to explore an indoor environment. In addition to that, the MACS carries the RACS with it. Once the MACS reaches a tight door which it cannot pass, it deploys the RACS in front of the door, to let it explore inside of the room, and continues its work in another location. The MACS is equipped with a special container to place the RACS on it.

Between the works of Hirose et al. [HSF94] and Anderson et al. [AMR96] there are certain similarities but also differences. The similarities are:

1. Both of them considered physical relationships between robots.
2. Both of them used a robot to carry its colleague.
3. All team members share the same mission (i.e. exploration).
4. Robots depend physically on each other for a period of time (temporary dependency).

The differences are:

1. Hirose et al. [HSF94] used a homogenous team while Anderson et al. [AMR96] used a heterogeneous team.
2. The position of each robot within the physical relationship is not exchangeable in Anderson's work while it is exchangeable in Hirose's work. In other words, the MACS cannot exchange its position in the relationship with the RACS to being carried by the RACS, while the robots in [HSF94] can exchange their positions within the physical chain.
3. Although the robots share the same mission in [AMR96], they cannot exchange their work locations without a negative impact on their work performance. The MACS cannot enter the target work location of the RACS because of its size while the RACS needs a longer time to cover the MACS' work location. The robots in [HSF94], on the other hand, can exchange their work locations without a negative impact on their performance.

These differences and similarities are the characteristics which distinguish the marsupial relationship from other physical relationships in robotics. On the one hand, the differences differentiate the marsupial relationship from other homogenous relationships. The heterogeneity of the team members is the key reason behind this decision. The similarities, on the other hand, form the marsupial relationship as a special case of the physical heterogeneous relationships. The carrying process is the main distinction between the marsupial relationship and other physical heterogeneous relationships. Furthermore, the dependency between Container and Passenger is temporary in the Marsupial relationship.

Several definitions tried to touch one of these characteristics to define the marsupial relationship. Murphy et al. [MAB+99] were the first research team who established this term. They used it to relate the robots' behaviour to the kangaroo lifestyle where a big robot ("mother robot") carries one or more small robots ("child robots"). It is worth mentioning that Anderson et al. [AMR96] were the first research group who addressed the marsupial relationship, but did not term it.

Ausmus et al. [ABE+] defined the marsupial robot as a group of mobile robots, a sub-group of which depends on other group members for transport, feeding, etc. This dependency can last either for a short period of time or for the entire mission. Despite the fact that Ausmus' definition narrows Murphy's definition, it does not consider the characteristics of the marsupial. Ausmus et al. [ABE+] called the Container Robot the Dispensing Agent and the Passenger Robot the Passenger Agent. Another notation for Container and Passenger was presented by Matusiak et al. [MPA+09] who named them Motherbot and Marsubot.

Leitner [Lei09] extended Dudek's taxonomy [DJMW96] by adding a special class for the marsupial relationship COMP-MAR. This class defines the physical relation of the marsupial. However, it does not refer to the characteristics and the roles of the marsupial members.

Since none of these definitions give a precise description of the marsupial relationship and its characteristics, we present a precise definition as follows:

A marsupial relationship is a physical relationship between two or more heterogeneous mobile robots, which the robots establish to utilize their individual strengths and to overcome their individual weaknesses. This relationship is essentially used for the carrying process. The robots which are acting as carriers cannot exchange this role with their Passengers within the same application domain as well as they cannot exchange their target work locations with their Passengers without a negative impact on the performance of the involved robots. During this relationship, the dependency among the robots is temporary.

By the same application domain constraint we mean that if robot *R1* is the Container for robot *R2* on the ground *G* (the marsupial application domain), *R2* cannot be the Container for *R1* on *G*. However, this constraint does not prevent *R2* from being the Container for *R1* on another application domain, like in the sky. Moreover, it does not prevent *R1* from being a Passenger of another robot *R3* on *G* (i.e. nested marsupial).

3 The Roles of the Marsupial Members

Two types of robots are needed to form a Marsupial relationship (i.e. Container Robot and Passenger Robot). The container roles are elaborated in Sect. 3.1 and the passenger roles are elaborated in Sects. 3.2 and 3.3.

3.1 The Container Roles

Murphy et al. [MAB+99] mentioned four roles for the Container: Coach, Manager, Messenger, and Carrier. However, these roles do not cover the other possible roles of the Container Robot which are presented in the state of the art. Therefore, we add two more roles: the Processor and the Supporter. We elaborate each role and distinguish it from other Container roles. A Container Robot can play several roles during the execution of a task.

3.1.1 The Carrier Role

The Carrier Role is the fundamental role which forms the marsupial relationship. All Container Robots play this role. Within this role, a Container carries its Passenger Robots either inside of a closed box [ZCWT08, Mur00], inside of an open box [KP03, DBK+02], by using a gripper [FAS+] or on its top [SHK+05, KP03, Web10]. The purpose of this role is to deliver the Passenger Robots faster to their deployment point, to save their energy, and to protect them during the carrying process. Anderson et al. [AMR96] introduced a conceptual approach where the Container deploys the Passenger and a network hub to facilitate the communication to the Passenger. Once the Passenger finishes its task, it moves toward the network hub and waits for being collected by the Container.

3.1.2 The Coach Role

Generally, a Container Robot has two advantages which can be exploited after deploying its Passenger Robots at the target location.

1. The Container Robot can change its position to get another angle of view on the work location, since it can move freely after the deployment of its Passenger Robots.
2. The Container can be provided with various sensors to monitor the Passenger Robots and to work as an additional provider of information.

These advantages enable the Container Robot to act as a Coach by sending directive messages to its Passenger Robots. Zhou et al. [ZCWT08] used a marsupial fish-like robot where the Container assists the Passenger with the Passenger's task.

3.1.3 The Manager Role

Acting as a Manager means that the Passenger Robots get their commands directly from the Container Robot. The Container sends a specific task to each Passenger.

The difference between the Coach Role and the Manager Role is the type of the message. As a Coach the Container broadcasts directive messages to its Passenger Robots and each Passenger interprets these messages based on its situation. As a Manager, in turn, the Container sends specific commands to each individual Passenger. Each Passenger has to execute its specific commands [ABE+].

Sukhatme et al. [SMV01] elaborated the Manager Role by using a marsupial aerial team of robots. The Container Robot is an unmanned aerial vehicle (UAV) which carries an unmanned ground vehicle (UGV). The Container Robot releases the Passenger and assigns a task to it. Once the task is accomplished, the Container Robot collects the Passenger.

3.1.4 The Messenger Role

Either the conditions at the target location (e.g. underground and underwater), the limited capabilities of the Passenger, or both make the communication between it and the external world difficult. To overcome this obstacle, a Container acts as a messenger between its Passenger Robots and the external world on the one hand, and between the Passenger Robots themselves on the other hand. This service can be used by a Passenger either through wired communication with the Container (e.g. [MAB+99]) or through wireless communication (e.g. [ZCWT08]). Generally a cable is used when the Passenger is already connected with the Container via a rope (e.g. [MAB+99]). Regarding the wireless communication, Zhao et al. [ZLLZ08] gave the marsupial team the ability to install a repeater between the Passenger and the Container. This repeater is needed either because of signal disruption or the weakness of the Passenger's capability. Anderson et al. [AMR96] used the repeater as a landmark to help the Container with the collection of the Passenger, in addition to its hub functionality.

3.1.5 The Processor Role

Within this role, a Container Robot shares its computational capability with its Passenger Robots to overcome their weaker computational capabilities. This sharing happens on request from the Passenger. The Passenger Robot sends its input data to its Container. The Container, in turn, processes these data and returns them to the Passenger.

Initiating the communication session and determining the number of Passenger Robots which are involved in this communication session distinguish the Processor Role from the Coach Role and the Manager Role on the one hand and from the Messenger Role on the other hand. These differences are sketched in Fig. 1.

1. In the Coach Role and the Manager Role, the Container Robot initiates the communication session to send messages to its Passenger Robots (The Manager Role section shows the difference between the Coach Role and the Manager Role). But, in the Processor Role the Passenger Robot initiates the communication session with its Container Robot.

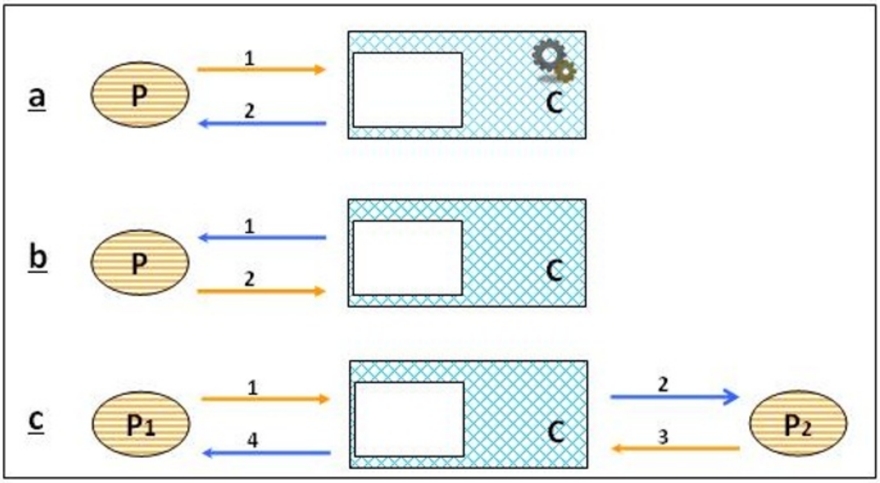

Fig. 1 A sketch of Marsupial members. C stands for Container Robot and P stands for Passenger Robot. The *numbers above the arrows* indicate the messages' sequences. **a** sketches a Processor role where the Passenger Robot initiates the communication. **b** sketches a Manager role where the Container Robot initiates the communication. **c** sketches the Messenger role where the Container Robot passes messages between two Passenger Robots; like in **a** the Container Robot exchanges messages with one Passenger Robot and processes the message

2. In the Messenger Role, the Container passes the messages either among Passenger Robots or between Passenger Robots and the external world. However, the Container Robot, which plays the Processor role, exchanges messages just with one Passenger Robot and processes the requested data from its Passenger.

The Processor role is addressed by Rybski et al. [RSE+00] where four Passenger Robots depended partially on a Container Robot to process their sensor data.

3.1.6 The Supporter Role

This role includes the other logistic issues which require a physical interaction between a Container and its Passenger Robots on the one hand, and between the Container and the target environment on the other hand.

1. The physical logistic interaction between them includes for example recharging batteries [MAB+99]. This role is used when Passenger Robots are working for extended periods of time or the time which is required to accomplish their tasks is unknown. A Container provides its Passenger Robots with power either through a cable or through a docking station. Murphy et al. [MAB+99] used the cable approach to provide the Passenger with power. This approach limits the movement of the Passenger and the cable could be cut because of harsh terrain. Matusiak et al. [MPA+09] presented an approach to recharge the Passenger

Robots' batteries through docking stations inside of the Container's body. Their Container Robot was able to feed three Passenger Robots at the same time. Feeding six Passenger Robots at the same time by one Container was presented by Kottas et al. [MAB+99]. Despite the fact that the docking approach gives Passenger Robots the freedom of movement, the Passenger Robots have to reserve part of their time for travelling back to their Container in order to recharge their batteries.

2. The physical logistic interaction between the Container and the target environment is for example removing obstacles which the Passenger faces (e.g. opening a closed door) and carrying the required equipment which is used by the Passenger to accomplish its task (e.g. first aid tools [ZLLZ08]). Stroupe et al. [SHK+05] presented a conceptual approach where a team of small space robots is carried by a large spider robot. Besides the Passenger Robots, the Container carries an orbital replacement unit (ORU). The mission of the marsupial team is to assemble and maintain an orbital unit in space. The Container Robot puts the ORU in its target place. After that, the Passenger Robots fix and connect this unit with the other units.

3.2 The Passenger Roles

The marsupial relationship exists in order to provide Passenger Robots with the required logistic services to accomplish their tasks smoothly. This means, the Passenger Robots are the service consumers. Therefore, most of the research works did not present roles or even contributions of Passenger Robots in the marsupial relationship. Instead, they assigned tasks to the Passenger after the deployment process. These can be surveillance [RSE+00], exploration [KP03], reconnaissance [FAS+], communicating with trapped victims [Mur00], and providing them with the required first aid tools [ZLLZ08], to name a few.

Murphy et al. [MAB+99] is the only exception of this trend. They presented a conceptual contribution of the Passenger Robots. In their work, the Container Robot, which plays a Manager Role, uses the sensors of its Passengers during the carrying process. For instance it uses them as extra mobile (non-attached) sensors while they are standing on its board.

3.3 Discussion

Some of the Passenger Robots' tasks could be seen as roles for these Passenger Robots. The project of SPAWAR Systems Centre (SSC) [Web10] is an example of these illusionary roles. In this project [Web10], they used Passenger Robots to expand the Container's force protection in military applications. Another example is presented by Sukhatme et al. [SMV01]. They introduced a case study about an aerial Container Robot which uses its ground Passenger Robot to gain information about ground regions which the Container cannot cover from the sky.

These illusionary roles and others are reflections of the Container's roles, more precisely the Manager Role. A Container Robot, which has a Manager Role, sends specific tasks to each specific Passenger. The Passenger Robots, in turn, perform these tasks.

The confusion occurs when the Container Robot gains benefits from some of these tasks such as expanding its force protection [Web10].

To distinguish illusionary roles (e.g. [Web10]) from actual roles (e.g. [MAB+99]), we consider the carrying process as a distinction. If the Passenger Robot performs its task during the carrying process, it is an actual role. Otherwise, it is considered as an illusionary role.

Based on this rule, the Passenger Robots in [MAB+99] have an actual role because they perform the role during the carrying process, whereas the Passenger Robots in [SMV01, Web10] have illusionary roles because they perform their tasks after the deployment process.

4 Application of Marsupial Robots

Within this section, different applications of marsupial robots are discussed. The environment of the Container is used to organize this section in five categories: Space, Aerial, Ground, Underground, and Underwater marsupial.

4.1 Space

Stroupe et al. [SHK+05] presented a conceptual approach of a marsupial team in space. The Container Robot is a spider-like robot while the Passenger Robots are a team of Limbed Excursion Mechanical Utility Robots (LEMUR). The mission is to assemble and maintain an orbital unit in space. The Container Robot plays a Supporter Role and the Passenger Robots have construction and maintenance tasks. Both of them are working autonomously.

4.2 Aerial

Sukhatme et al. [SMV01] presented a case study about an aerial marsupial robot team. The Container Robot plays a Manager Role and is an UAV, while the Passenger is an UGV. The mission of this marsupial team is to detect and track an intruder on the ground. If the Container cannot track the intruder from the sky, it deploys the Passenger to follow the intruder on the ground. Once the intruder appears again, the Container collects the Passenger and starts tracking from the sky.

4.3 Ground

Anderson et al. [AMR96] introduced the first marsupial team of robots. In their work, the Container Robot plays both, a Messenger Role and a Processor Role. The Container and the Passenger are UGVs. The mission of this marsupial team is to explore and map an indoor environment. Murphy et al. [MAB+99] addressed this mission by using a tethered marsupial team of robots where the Passenger is tied with the Container. Examples of other works that addressed the UGV Container with one or more UGV Passenger Robots are [KDP09, MPA+09, KP03, DBK+02, RSE+00].

Using an UGV Container with an UAV Passenger was addressed by the project of SPAWAR [Web10]. In their research work, the marsupial team is used for military applications. The Container Robot plays a Messenger Role and a Supporter Role and the UAV Passenger expands the force protection of the Container. Besides the UAV Passenger, the Container has an UGV Passenger as well. Therefore, this work is the first work which applies heterogeneous Passenger robots on a real test bed.

Dealing with an underground Passenger was addressed by Ferworn et al. [FAS+]. They used an UGV Container with an underground Passenger where the Container plays a Carrier Role. Once the Container reaches the target location, it drops the Passenger there. The mission of this team is urban search and rescue.

4.4 Underground

The underground marsupial team is addressed by Zhao et al. [ZLLZ08]. The Container Robot plays a Supporter Role and a Messenger Role and is connected to a remote control centre via a rope. The Passenger is kept inside of a closed box. The mission of this team is to search and rescue trapped victims inside of a collapsed coal mine. Besides, this team establishes a communication between the human rescue team and the trapped victims.

4.5 Underwater

Zhou et al. [ZCWT08] presented a fish like marsupial robot team. The Container Robot plays a Coach Role and keeps the fish-like Passenger Robot inside of a specialized cabin. The mission of this team is to explore unreachable places such as underwater caves, sunken ships, and oil pipelines.

5 Summary and Open Issues

The marsupial relationship in robotics is a physical relationship among two or more heterogeneous robots. This relationship enables the heterogeneous robots to exploit their individual strengths and overcome their individual weaknesses. In addition, it provides several logistic services which expand the capabilities of the participating robots.

This physical relationship has a positive impact on Urban Search and Rescue (US&R) applications which need a fast and safe deployment of specific task robots either inside or near their target work location. Furthermore, the Container can be used as a mobile logistic station to provide a mobile service point which is near to its Passenger Robots' work location. Battery recharging is an example of logistic services the Container can provide.

This paper presents and discusses the state of the art of marsupial relationships. Besides, it specifies the characteristics of a marsupial relationship and uses these characteristics to come up with a new definition of this relationship. The marsupial relationship has been addressed by several research groups under different constraints and involving different roles. Moreover, the researchers applied it to different areas. We believe that this paper will play a key role towards accelerating the research progress in this field of robotics.

Some issues still need to be addressed such as:

5.1 Efficient Rendezvous in Marsupial Relationships

The process of collecting the Passenger Robots by the Container Robot has an important effect on the performance of the robot team. This can be seen when the Container plays a Supporter Role. If the Container is not able to attend the agreed rendezvous with one of its Passenger Robots, the Passenger Robot fails to continue its work either temporary or permanently (e.g. because its battery is discharged).

5.2 Parasitistic Marsupial-Like Relationship

This special case of marsupial relationship describes an ad hoc relationship between two heterogeneous robots. The formation of this relationship is carried out by the Passenger Robot and without prearrangement with the Container Robot. This means, a robot *R1* utilizes the physical capability of another robot *R2* to facilitate *R1*'s work, without any negotiation with *R2*.

5.3 Nested Marsupial Relationship

The typical marsupial relationship is formed by a Container and one or more Passenger Robots. In the nested relationship, a Container Robot acts as a Passenger of another Container.

A suggested application for this marsupial robot is a rescue mission inside a burning nuclear plant. Due to harmful radiation, a safe distance should be maintained. At the same time, a quick deployment is required inside the plant. This scenario could be achieved by using a nested marsupial which consists of an UAV as an outer Container and an UGV as an inner Container. The inner Container, in turn, has a UGV Passenger Robot.

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Self-Optimising Assembly Systems Based on Cognitive Technologies

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Abstract In the field of assembly planning, optimisation approaches are often limited to partial evaluations of the value creation chain due to complex interactions between the components of the production system. The usage of situational adaptive systems helps to reduce the risk of overly focusing on individual elements without considering side-effects. Especially integrative, self-optimising structures offer great potential for improved planning efficiency.

In this research a three-layered assembly planning model was established and implemented. The developed software structure includes a hybrid approach with offline planner, conducting all preliminary analysis with an assembly-by-disassembly strategy, and online planner, evaluating this information during the assembly to derive a suitable sequence for the current production situation. Furthermore a cognitive control unit is responsible for the decision-making and executes appropriate actions. For validation, a robot-supported assembly cell is presented.

Two series of experiments were conducted to develop a concept that adapts the system behaviour to operators' expectations by using human-centred process logic. Additionally a lab study was designed to investigate the visual presentation of information to humans.

The work achieved a scientific examination of cognitive mechanisms in automation. It shows that cognitive automation of production systems enables an efficient and robust assembly of diversified product families. This effectively makes customer-oriented mass production possible and offers high-wage countries considerable competitive advantages.

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1 Introduction

Like business and production processes, entire production systems are often based on hypotheses that only provide a partial view of the value-adding chain or result in specific technological interactions. We rarely fully understand the way that processes, materials, production resources and humans interact or how this affects the product itself. It is impossible to predict how changes will impact on value creation as a whole. Because it is so difficult to gain an integrated view, optimisation processes often only focus on individual elements of a system. Existing ways of optimising the behaviour of a single element can become the focus of too much attention and can tie up resources even though, in certain situations, doing so can have a negative impact on behaviour in other areas of the system.

The solution to this conflict lies in designing a system that can adapt its goals according to the situation. While most system optimisation processes happen externally – i.e. a human controls them – having the system itself perform them can be an interesting option in many cases. However, developments in automation show that, even in comparatively simple situations, we still have work to do to achieve this goal. This means that humans often still play an important role in system optimisation. Implementing self-optimising capabilities offers great potential for resolving issues associated with planning efficiency.

Using cognitive functions as a basis, it is possible to take parts of the original range of tasks – like detailed algorithmic planning of an assembly process, and rule-based re-planning and adaptation planning – and transfer these from humans to the machines themselves. The first step in achieving this involves designing and developing a software architecture that is capable of fulfilling the specific requirements of a cognitive system, such as independently planning actions and executing them. This architecture is based on a three-layer model that is expanded to include modules for knowledge representation and human-machine interaction. The deliberative part of this architecture – the planning layer – is where the actual planning and decision-making happens, through targeted linking of production rules. A hybrid approach is used to achieve a flow-oriented, error-free assembly of randomly fed-in components. The approach combines traditional planning processes (an "offline planner") with reactive cognitive control (an "online planner"). Prior to execution, the machine's offline planner calculates the complex geometric analysis steps for assembly planning. This involves an assembly-by-disassembly strategy, which identifies all the assembly steps necessary to bring together individual components into a finished product. To do so, all possible pairs of subsets of components are disassembled and checked to establish whether this can be done collision-free. This process is repeated until the product has been completely disassembled. Because an assembly action can reverse every disassembly action, read backwards the disassembly steps produce all possible assembly steps. The results of this preliminary analysis are recorded as a state graph. The edges in the graph are weighted with cost values for the different work steps and also show information on any additional components needed. Weightings for the different interim states are also assigned to the nodes in the graph.

The online planner can evaluate this information during assembly to derive a suitable assembly sequence for the current production situation and a given target system. This involves updating the state graph on the basis of the available components and the current state of the partially assembled product. Next, the A* algorithm is used to calculate the best route from the current state to the target state (the end product). Under the prevailing boundary conditions, this path represents the optimal assembly sequence. The next work step involves investigating the assembly sequence to identify possible parallelisable assembly actions. The parallelisable actions are then combined in such a way that the assembly plan is made up of a sequence of sets of assembly actions that can be executed at the same time. This plan is then passed on to the decision-making component – a cognitive control unit (CCU) based on SOAR cognitive architecture – where it serves as a basis for decisions. The CCU checks the current situation in cycles and initiates appropriate actions. Under normal circumstances, from the set of parallelisable actions to be executed next, the CCU randomly selects an action and implements it. In unforeseen situations, either re-planning is initiated or the human operator is requested to solve the problem. This process continues in cycles until the desired product has been fully assembled.

A robot-supported assembly cell is presented to validate the system. In addition to covering all key aspects of an industrial application (relevance), the cell can easily illustrate the function and flexibility of a CCU (transparency). The assembly cell has a conveyor-belt system, which is used to feed in components. There are two jointed-arm robots, of which only one is initially connected to the CCU. This robot can be moved along a linear axis and, in addition to having a flexible multi-finger gripper, is equipped with a colour camera to identify components. The second robot separately feeds in components on a conveyer belt. In the centre of the assembly cell there is a surface that can be used as a workspace and as interim storage for parts that cannot be used immediately. The human operator's workspace is currently located directly next to the surface, separated by an optical safety barrier. The workspace has a human-machine interface that can be either stationary or mobile. By displaying process information in an ergonomic way, the interface provides details on the system status and can, if necessary, help human operators to interactively identify and resolve process errors.

To enable humans to safely and effectively manage and monitor the process, machine-made decisions (e.g. on establishing the assembly sequence) must be presented quickly and in a way that is easy to understand and will ensure reliable implementation. Furthermore, the assembly sequence must be planned in a way that conforms to human expectations. With this in mind, a concept was developed that enables system behaviour to adapt to operators' expectations by using a human-centred process logic based on the MTM-1 system. This concept was validated using the assembly cell. Two series of experiments under laboratory conditions sought to establish whether humans followed certain easy-to-generalise strategies when carrying out an assembly task. The experiments identified and validated three assembly strategies as rules: 1) People begin assembling from edge positions; 2) People prefer to assemble adjacent to existing objects; 3) People prefer to assemble in layers. A specially developed simulation environment shows to what extent taking the identified assembly strategies into account as production rules within the knowledge base of the CCU makes it easier to predict the actions of the controlled assembly robot, and to what degree the rules can be generalised.

The presentation of results concludes with a lab study designed to investigate visually presenting information to humans. The starting point was the following scenario: a robot plans the workflow for a production task previously defined by a human operator and then carries it out. However, an error occurs during processing. Because the cognitively automated system is unable to identify the error itself, the human operator must be put in a position to quickly and safely identify and resolve the error. The study compared different ways of displaying the information, in order to find the fastest and most reliable one for interactive error identification. A subsequent comparison looked at the differences between a TFT screen in a workroom and a head-mounted stereoscopic display. The results showed that a display fitted over the field of view improved error detection rates.

The research results made it possible, for the first time ever, to achieve an integrated demonstration of, and carry out scientific investigation into, the design, development and application of cognitive mechanisms in automation using a robot-supported assembly cell to control them. The work also identified the need for further research into whether the results can be transferred to products widely used in industry, and to the ergonomic design of human-machine cooperation.

The cognitive automation of production systems offers a technology that, with the same or even less planning effort, can efficiently and robustly automate product families with large numbers of variants – even in cases where only small numbers of each variant are produced. This effectively makes customer-oriented mass production possible. Cognitive mechanisms in automation offer high-wage countries in particular the chance to achieve considerable competitive advantages, and thereby to directly contribute to securing and expanding their own production locations.

2 State of the Art

Autonomous production cells can be considered the predecessors of cognitively automated production systems. They are mainly characterised by physical process models integrated directly into the machine control system and by machine operation and monitoring based on these models. Safe, effective human-machine interaction means that even complex handling processes can be carried out error-free over an extended period of time, and that the work system can be operated at the optimum level in terms of performance and operational requirements [Sch99, PS06]. However, automated production cells only have limited self-optimising planning functions; these functions are crucial to the concept of cognitive automation. The work of Onken & Schulte [OS10] built on these functions and helped to shape the concept of cognitive automation and introduce it to the scientific community. But the original concept focuses heavily on using the technology in unmanned vehicles and is therefore only partially applicable to production systems. Although the corresponding concept of the "cognitive factory" [ZBS$^+$09] shows that cognitive mechanisms can be successfully integrated into manufacturing systems, the overriding subject of automation using cognitive models that incorporate the "human factor" for machine operation and monitoring has remained largely unexplored.

To present the current status of research into cognitive automation in production with a view to application in assembly contexts, we must look at a number of different aspects. In view of the research results presented in Sect. 2.1, what follows will focus on four central aspects: (1) Software architectures for cognitive systems; (2) Planning assembly sequences with formal methods; (3) Industrial automation; (4) Task allocation between humans and machines.

2.1 Software Architectures for Cognitive Systems

With regard to designing and developing automated robotic systems, numerous architectures have been proposed as basic structures for simulating cognitive functions [KST06, Gat98]. These software architectures combine a deliberative part for the actual planning process (planning level) with a reactive part for direct control (action level). A widely used approach here is the three-layer model that comprises cognitive, associative and reactive control layers [RN03, Pae06]. The lowest layer (reactive) contains the components that control information processing, and is designed to influence system behaviour in such a way as to ensure that the required reference variables are achieved quickly and accurately. The associative layer monitors and controls the system. The majority of rule-based auxiliary functions for automation – like process control, monitoring processes and emergency processes, and adaptation routines for improving system behaviour – are all embedded here. In this top layer, the system can apply "reflexive" methods (e.g. planning and learning processes, model-oriented optimisation processes and knowledge-based systems) to use knowledge about itself and its environment to improve its own behaviour. The focus here is on the system's cognitive ability to carry out self-optimisation.

The software architecture used in Collaborative Research Centre (CRC) 614 – "Self-optimizing concepts and structures in mechanical engineering" – picks up on this model [GRS09]. The Cognitive Controller from the Technische Universität München is also based on a multilayer model. The signals from the production system in question are prepared and processed by a standard controller and by a cognitive safety controller. Additional general studies of cognitive systems can be found in Onken & Schulte (2010) and, regarding the production environment in particular, in Ding et al. [DKSS08]. The latter focuses on implementing cognitive capabilities in security systems for plant control. As such, the study pays particular attention to safety in human-machine interaction and to safety in the workplace.

Complementary concepts and methods can be found for automobiles and air and space travel [Kam08, Put04]. Particularly noteworthy here are the various architectures used by the winning teams in the DARPA Grand Challenge, a competition for driverless ground vehicles. These architectures provide regular insight into the latest research [Thr08, Kam08]. Many of the architectures are modelled on a "relaxed layered system". In this system, every layer can use the services of the layers below. This makes the system more flexible and efficient by ensuring that every layer is fully supplied with information [Urm08].

This shows that modified architecture models are used to configure and develop cognitive systems. We can see that the most-used approach involves combining the multilayer model with other models. The final architecture must therefore be adapted to the specific application to ensure the highest level of system performance.

2.2 Planning Assembly Sequences Using Formal Methods

"Planners" play a major role in cognitive systems. There are numerous formal approaches to solving planning tasks in different fields of application. Hoffmann [Hof01] developed the Fast-Forward Planner, which is capable of deriving actions for given problems in deterministic operational areas. By contrast, other planners can handle uncertainty [HB05, CGT01]. All the planners mentioned are based on a symbolic knowledge representation. In the case of assembly planning, which requires the geometric relationship between conditions and their transitions to be adequately represented, this kind of knowledge representation becomes extremely complex, even for simple tasks. As a result, generic planners fail when it comes to calculating assembly sequences with even a short-term planning horizon.

Other planners have been specially designed for assembly planning. They work directly with geometric information to derive action sequences. A popular approach is the Archimedes system [KWJ+96], which uses and/or graphs for formal representation, and the assembly-by-disassembly strategy to dismantle the end product into its individual components. Thomas [Tho08] picks up on this concept and develops it in such a way that the system requires no additional help from the user to deduce all possible disassembly steps for the end product – as was the case with the Archimedes system. Thomas only uses geometric information about the end product and the components it contains. This approach, however, is not capable of dealing with "uncertain" planning data. We can find another approach in the assembly planner developed by Zaeh & Wiesbeck [ZW08], which calculates action sequences almost independently. However, it is not designed to control a technical system, but as a support system for manual assembly. This means that the decision to carry out the sequence is made by a person, not a machine.

2.3 Industrial Automation

Industrial automation comprises many different controllers which, by working together, enable production plants to function. The components of an automation system used in production are usually assigned to different levels (DIN EN 62264). The lowest level houses the sensors and actuators used to detect and change the state of a production plant. Sensors and actuators are linked, either directly or via fieldbuses, to device controllers. Depending on the machine type to be controlled, in manufacturing technology either a programmable logic controller (PLC), numerical control (NC), robotic control (RC) or motion control (MC) will be used. Each machine can then be controlled by one device controller or more. Groups of machines are combined to form cells, which are coordinated using device controllers. Depending on its size, an entire production plant comprises several cells and is controlled by a manufacturing execution system (MES).

The most commonly used device controllers are designed to meet the demands of "traditional" industrial automation. They are programmed using languages that are partially reminiscent of circuit diagrams, or using machine-like programming constructs that provide maximum control over the relevant device or group of devices [61103].

The models and algorithms necessary for self-optimisation are not currently part of device controllers. It is only at the control level that "intelligent" planning algorithms come into play [BKH08] and the concept of multi-agent systems is used [Bre03]. The prevailing programming paradigms in automation result in rigidly linked processes at the cell level and the device level.

In automation the term "intelligence", applied to the lower levels, is often taken to mean adaptive control. However, intelligent decisions on targeted action, which are necessary for assembly, are taken at the cell-control level and, in automated solutions, implemented in controlled movements. As a rule, using PC-based cell controllers [PD06, Upt92] in industrial environments also makes it possible to use the SOAR cognitive architecture employed in this project.

2.4 Task Allocation Between Humans and Machines

Looking at the role humans play in standard automated production, we see that their main task involves managing and monitoring the manufacturing system. In the event of a malfunction, they must be able to take over manual control and return the system to a safe, productive state. This concept, termed "supervisory control" by Sheridan [She02], involves five typical, separate subtasks that exist in a cascading relationship to one another: plan, teach, monitor, intervene, learn (see Fig. 1).

After receiving an (assembly) order, the human operator's first task usually involves planning the assembly process. To do so, he or she must first understand the functions in the relevant machine and the physical actions involved to be able to construct a mental model of the process. Using this basic understanding, the operator

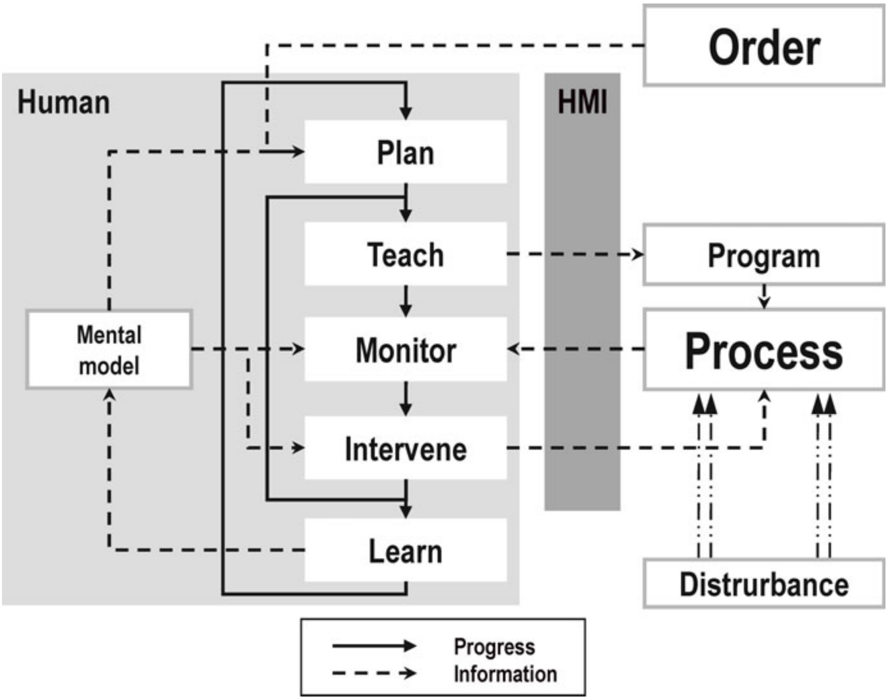


Fig. 1 Supervisory control (based on Sheridan 2002)

then develops a concrete plan that contains all specific sub-targets and tasks necessary. "Teaching" involves translating these targets and tasks into a format that can be used for machine control – e.g. NC or RC programs that facilitate a (partially) automated process. This process must be monitored to ensure that it runs properly and produces products of the desired quality. The expectations for the process are drawn from the mental model the operator created at the start. In cases where reality deviates significantly from the model or where there are anomalies, the human operator can intervene by modifying the NC or RC program or by manually optimising the process parameters, for example. Ultimately, every intervention involves the human operator continually adapting his/her mental model, while existing process information, characteristic values and trend analyses help the operator better understand the process and develop a more detailed mental model.

With a cognitively automated system, the tasks change gradually, but in a conceptually relevant way (see Fig. 2). Because the cognitive control unit (CCU) can independently solve a certain class of rule-based production tasks, the human operator is relieved of performing repetitive, monotonous or very dangerous tasks. In a cognitive production system, the human operator defines the assembly tasks based on the status of the sub-product or end product, carries out adaptations or sets priorities as needed, compiles rough process plans, and sets initial and boundary conditions. The information-related pressure on the human operator is considerably

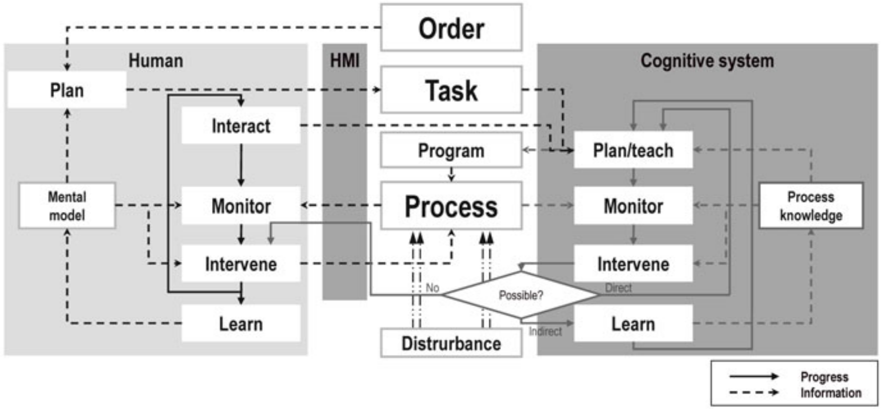


Fig. 2 Extended supervisory control approach for cognitive systems (based on [MOGS08])

reduced in the areas of detailed planning and teaching, because the cognitive system handles them. But shifting this load from the human to the machine can result in the human operator forming an insufficient mental model of the state variables and state transition functions in the assembly process. This is because knowledge relating to execution is already stored in the system's process knowledge. At the same time, however, humans must monitor system status and dynamics, and possibly make decisions based on this knowledge. Especially in the event of an error that the system cannot identify or solve, the human operator must receive all information relevant to the situation in an easily understandable form so that he/she can intervene correctly and enable system recovery.

3 Motivation and Research Question

In high-wage countries, automating production systems can cover over 70 percent of their functions. Given the law of diminishing marginal utility, raising the degree of automation even higher will not necessarily lead to a significant increase in productivity. Although automation can, as a rule, reduce the frequency of process errors, it also causes a disproportionate increase in the possible consequences of a single error [KFH^{+}08]. These relationships, which Lisanne Bainbridge incisively referred to as "ironies of automation" in 1987, are represented in Onken & Schulte (2010) as a negative feedback loop (vicious circle). To circumvent human shortcomings, a function that humans originally performed is automated. This increases the complexity of the system, which in turn places greater demands on the employee responsible for monitoring the automated function. The result is that the entire system potentially becomes less robust. The loop comes full circle when humans attempt to use automation again to compensate for these possible weaknesses. While it is not uncommon for an automated system's productivity to increase during the first iteration of the loop, humans often underestimate or even ignore the risks involved. Onken & Schulte (2010) believe that using mechanisms borrowed from human cognition presents an opportunity to "break the cycle" and design a flexible production system in which humans and machines work together safely and effectively – especially in process planning and monitoring, and in disturbance management.

A system that is capable of learning and of adapting to changing environmental conditions can increase planning efficiency by reusing acquired knowledge and transferring it to similar, new production cases. This can sometimes considerably reduce the number of iteration steps involved. Systems of this kind are known as self-optimising systems [FGK+04]. Self-optimisation requires cognitive capabilities that, in current production processes, only humans possess.

In this context, the term "self-optimising production systems" describes a concept that can implement value-stream-oriented measures at the same time as increasing planning efficiency and improving process and product quality [SB07]. Transferring existing knowledge to similar or new production cases – the essence of self-optimisation – opens up new perspectives for production and assembly systems by enabling them to dynamically adapt system behaviour to keep pace with changing targets and situations. Incorporating humans' unique skills and experiences into the system is considered essential to self-optimisation. Innovative cognitive functions in the form of symbol-processing systems should support humans and, where necessary, relieve them of routine tasks.

Here, cognition is understood to mean processes such as perception, knowledge storage, reasoning and learning. Obviously software can only partially simulate the unique features of human cognition, but some models [Str95] can be partially transferred to technical systems and thereby provide a suitable basis for self-optimisation. Thus, cognition can largely be described as referring to the transfer and application of knowledge, and to the processing of information, either by a living being's central nervous system or in an artificial system [Str95]. Within this context, the sub-project described here, which is concerned with self-optimising production systems, focuses on designing and realising a prototype of a CCU. This CCU can use symbolic knowledge representation to optimise itself according to predefined criteria. Most importantly, however, the CCU can be designed, developed, and operated safely and efficiently by highly qualified experts in a high-wage country like Germany.

Developing the design starts with the dilemma of planning orientation and value orientation in the polylemma of production [SO07]. In planning-oriented production, processes in a manufacturing system are centrally planned during operations planning and scheduling, in great detail, far in advance, and in line with the Taylorist principle of separating preparation and execution. Doing so makes it possible to closely align production steps with the overall target because all activities are analytically derived from the desired end result using a global target function. In value-oriented production, planning activities overlap with the actual value-adding process. In addition to carrying out the activity directly related to value creation, the person responsible for production defines sub-tasks, their sequence, and the use of production resources. The overall target is therefore generated in collaboration:

organisational units independently define their sub-targets and sub-tasks, and these come together along the process chain. This approach has the benefit of allowing the production system to respond quickly to changing boundary conditions, which means that it can better handle the complexities and dynamics of its environment and the process itself. State-of-the-art value-adding chains are typically only partially capable of independently finding top-down solutions to specific problems on the basis of simplified models within a defined solution space. As a rule, these chains do not fully take into account interactions between processes, materials, production resources and the people working in the environment, meaning that knowledge of these interactions is usually incomplete. The same is true of how these interactions affect the design of the product structure.

Cognitively automated systems should pave the way for new concepts and technologies for production and assembly systems that should be able – through continuous data analysis, information fusion, interpretation and assessment of the actual situation – to dynamically adapt themselves to changing targets and boundary conditions. The research question that arises from this is: how can we achieve a highly dynamic system while at the same time ensuring that the targets of all activities are well-synchronised?

The solution posited in designing and using cognitive automation is as follows: a cognitively controlled production system reacts faster, more reliably and in a more resource-efficient way than a production system that uses traditional planning logic and methodology. Unlike a standard control system, a cognitively automated system can, on the basis of internal decisions, independently redefine reference variables in terms of targets, and adapt the control strategy accordingly. It would, however, be naïve to believe that such a system could function completely autonomously. Scientific research must focus on designing and producing prototypes of cognitively automated production systems that can be further developed and efficiently operated by highly qualified skilled workers in high-wage countries. These are no longer purely technical systems; they are complex human-machine systems that require an ergonomic design. Therefore, in defining the research question, we can identify two fields of activity:

Firstly, this sub-project should address aspects of technical design and evaluating cognitive functions. Secondly, any design for this kind of future production system must focus squarely on humans and their superior cognitive skills.

The Cognitive Control Unit sub-project therefore explored the following research questions:

- Design and development of architecture for a cognitive control system: The requirements placed on a cognitive machine control system are reflected in the unique requirements placed on the software architecture of the system. The sub-project therefore investigates how this kind of architecture should be structured and designed. This involves taking into account the different time requirements for machine-oriented control systems (e.g. a robot cell) and planning for various data abstractions. The data flows and information shared between planning, control and human-machine interface must also be defined. A cognitive system works using a knowledge-based approach. This means that the software architecture must include components that allow the system to save and modify knowledge that machines can process and humans can understand.

- Design and development of a planning methodology for cognitive automation: Assembly planning presents a highly complex problem, even for current planning systems. If it also has to be flexible enough to adapt to unexpected events and ad-hoc changes in the process, we need to find special techniques for assembly planning and control that incorporate functions borrowed from human cognition.
- Usefulness of technical cognition in industrial automation: The numerous functions that have to be controlled in a production plant are predominantly designed to effectively and efficiently carry out a pre-defined process. Alongside the primary task (e.g. assembling a workpiece), supporting tasks also have to be controlled, such as transporting and handling the workpieces. To achieve end-to-end self-optimisation and control, all levels of industrial automation require cognitive functions. The sub-project therefore seeks to find out how to integrate cognitive functions into industrial automation, both conceptually and in terms of technical implementation.
- Human-centred design of a cognitive control system's knowledge base: A control system that has a knowledge representation which allows it to plan almost independently and according to the situation will have a considerable impact on the spectrum of tasks performed by human operators. Starting with the human role in this kind of cognitively automated production system, the sub-project uses robot-supported assembly to show how a human-centred CCU design can make system behaviour more compatible with the human operator's expectations. In doing so, the sub-project aims to develop a safe, productive and disturbance-free design for work processes in cognitively automated work systems.
- Ergonomic interface design: Another question relates to the way information is presented to human operators. One area that this research focuses on is ergonomically designing head-mounted displays and displays in workspaces using new methods of visualisation and interaction. In contrast to standard input and output media like keyboards and TFT screens, new technologies for user interfaces based on head-mounted, semi-transparent LCoS displays are being developed for use in production environments. They are also being ergonomically designed and evaluated with regard to their potential under operating conditions.

4 Results

4.1 Software Architecture

Russel & Norwig's three-layer model [RN03], widely used in robotics, was chosen as the basic framework for the architecture. Compared with other architectures commonly used in this field, such as the blackboard model [HR85], a three-layer

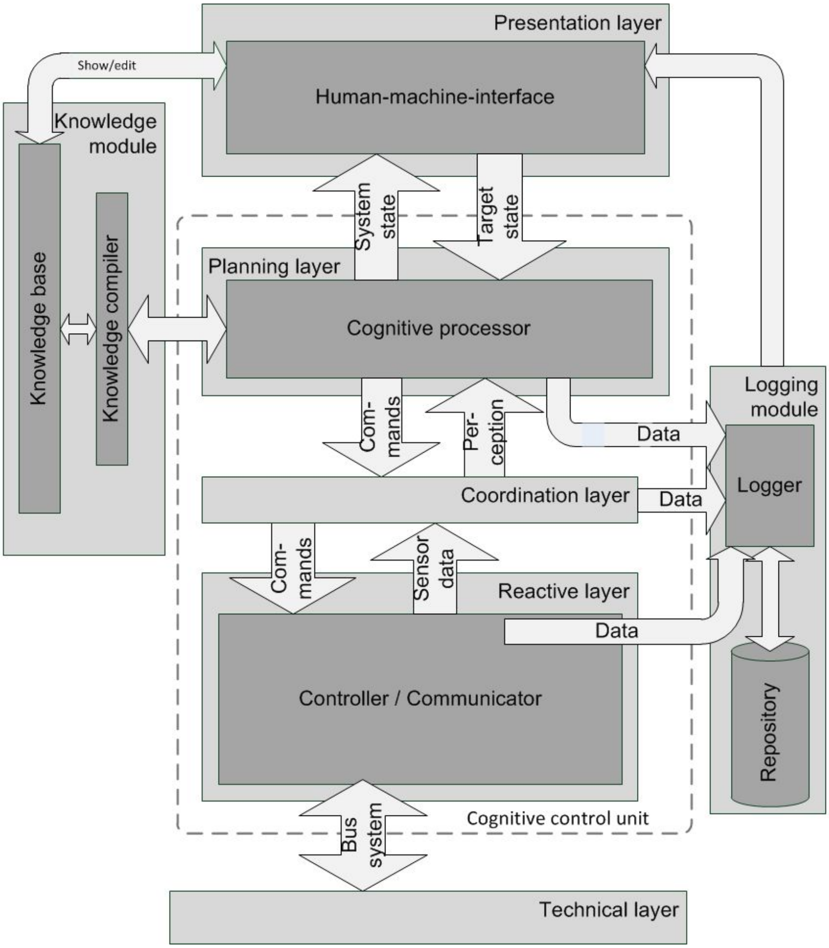


Fig. 3 Architecture for a Cognitive Planning and Control Unit

architecture has the advantage of a clear demarcation between abstraction levels and temporal demands. The planning layer operates on a high abstraction level with symbolic problem definitions and must satisfy only soft real-time demands. The reactive layer, on the other hand, has to monitor machine-related control loops in "hard real-time". The coordination layer mediates between these two layers. This is where abstract instructions from the planning layer are transformed into concrete machine control commands. In the reverse direction, the information from the various sensors is aggregated to form an overall picture of the situation and is transmitted to the planning layer as a basis for decisions.

In order to satisfy the demands of a holistic consideration of the human-machine system, the classic three-layer architecture was expanded to include further layers and modules (see Fig. 3).

The presentation layer forms the interface to the human operator. The interactive goal definition and description of the task, as well as the presentation of the current internal state of the CCU takes place by means of the human-machine interface. In addition, external data formats such as CAD data of the product to be assembled, are transmitted in internal representation forms and made available to the other components. The knowledge module contains the knowledge base of the CCU in the form of an ontology [Gru93]. The planning layer can send enquiries to the knowledge module by transmitting the system state received from the coordination layer. The knowledge module then analyses the objects contained in this state and can derive further information by means of reasoning via the ontology and transmit this to the planning layer. A further logging module forms the database for all the other components. All the data generated during system operation are persistently stored here so that in the event of an error, the cause can be reconstructed on the basis of the data if necessary. To support system transparency, all the data stored in the logging module during operation are accessible to the user via the presentation level. Furthermore, the data thus gathered can also be used for training measures that are integrated directly into work processes (embedded training, [OMGS07]).

The cognitive architecture SOAR, whose internal knowledge base is structured in the form of production rules (if-then rules), was chosen to simulate cognitive functions in the planning layer of the cognitive controller [LLK+01, LCS04]. Compared with emergent systems such as artificial neuronal networks, a rule-based approach has the advantage of not needing time-consuming and potentially unreliable preconditioning. To a certain extent, SOAR is able to simulate rule-based human decisions and to take over repetitive and monotonous process steps [HGH08]. It cannot, however, simulate genuine knowledge-based behaviour in the sense of reflecting on goals and their prioritisation (sensu [Ras86]).

As SOAR was not designed for automation applications and has no interface to industrial control systems, a framework was designed and developed which makes it possible to model the knowledge and the corresponding algorithms necessary for controlling the assembly and the logistics [Kem10]. Furthermore, it provides the architecture required for system control and the necessary interfaces. The planning layer, coordination layer, reactive layer and technical layer were developed for this purpose (see Fig. 3). The technical layer essentially consists of the kind of control units used in today's manufacturing cells. The character of the control interfaces is thereby more or less predefined: a robot controller, for example, processes travel commands with the pattern "Move linearly from A to B at speed C"; a PLC expects switching commands with the pattern "If input A is true, then set output B"; a special image-processing software that is located in the reactive layer due to its complexity and the real-time demands imposed by the application expects an order such as "Start object detection and feed back result". The function of the technical layer is therefore to control the individual devices via a defined interface protocol with defined semantics. The main functions of the planning and coordination layers involve dynamically generating the individual device-specific control commands from a global and relatively abstract description of the task, and coordinating their execution in accordance with feedback from the sensors. One example of a compo-

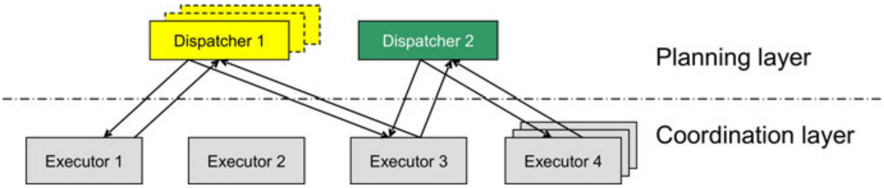


Fig. 4 Arrangement of the SOAR Dispatcher and Executor Agents in the Layer Model

nent in the reactive layer is the image-processing software mentioned, which, due to its frame rates, has to be located in this layer.

A SOAR agent that takes control decisions independently consists of the model of a given problem space and the mechanisms for its processing provided by SOAR. Each agent has its own long-term and short-term memory, and its own input and output areas, where it operates cyclically, in a manner comparable with the function of a PLC. The planning layer contains SOAR agents which are responsible for selectively assigning control instructions for the production system. One such "dispatcher" thus represents an order. The coordination layer contains agents which execute the control instructions, whereby each operation is represented by a dedicated agent, the "executor". This split between several agents takes into consideration the aspects of hierarchisation and parallelisation ([Kem10], see Fig. 4).

However, a control architecture is characterised not only by layers and interfaces, but also by the way in which the internal temporal sequence is organised. The cognitive control architecture is generally based on a fixed processing cycle, comparable with the well-known behaviour of a cell controller in the form of a PLC. Similarly to that, the length of a processing cycle in this case also depends on the number and complexity of the active agents. Since there is no real-time operating system, no hard real-time can be achieved here. But this is generally not necessary for the execution and decision layers. The real-time-critical processing takes place in the reactive and technical layers. The SOAR agents are instantiated as independent objects of the agent class. First the active dispatchers are executed sequentially, then the executors. This means that decision and execution phases are always synchronous with one another. The same applies to the input and output or simulation. As a result, all the agents operate with the same image of the environment during a control cycle, and are therefore quasi-parallel; this also applies to the exchange of messages between the agents. A relatively simple but efficient scheduling policy is employed for the individual agents: an agent continues to receive computing time until it generates an output to the controller. This is frequently the case after one SOAR decision cycle, but in some situations the agent requires several cycles before it reaches a decision. All the agents run in one thread with the SOAR kernel and are processed in a fixed sequence. This process is flanked by two additional measures:

- To avoid endangering the control functions at execution level, measures must be taken to ensure that an agent does not take too long (e.g. during virtual planning). This is achieved by ensuring that it is always the next agent's turn after a specified maximum number of decision cycles have elapsed. This also means that decision processes of individual agents can extend over several control cycles.

- As only a limited number of resources are available at the decision level, a dispatcher at the front of the execution sequence tends to have an advantage. Users can prioritise production rules relative to one another. However, if they do not do this, the process follows the principle of "fairness" and the execution sequence in each SOAR cycle is defined at random.

Asynchronously to the actual processing, user inputs can be made for process control and visualisation, with semaphores ensuring data consistency.

4.2 Hybrid Method for Assembly Planning and Control

Starting from the general function of the CCU, which involves carrying out the planning and control of a robot-supported assembly process on the basis of production rules in conjunction with a formal-mathematical product model, this section initially deals with only the cognitive processor. As already mentioned, this is located in the planning layer. In the validation study presented here, the only input the CCU receives is a description of the finished product to be manufactured. "Action primitives" stored in the knowledge base of the CCU in the form of production rules serve as control commands for the industrial robot for component assembly, and are also linked in the processing cycles by the processor, depending on their state, to create a complete and efficient assembly process.

Simulation experiments investigated the influence of various factors on the dependent variables "CCU processor time" and "number of assembly cycles" in the whole process of assembling the target product (MTM-1 cycles, see Sect. 4.5. The target product consisted of identical parts. The independent variables of the simulation experiment are: (1) The size of the target product (six levels: 4, 8, 12, 16, 20 or 24 parts); (2) The number of parts fed in on the queue (seven levels: 1, 4, 8, 12, 16, 20 or 24 parts); (3) The type of feed-in (two steps: deterministic feed-in of the parts required or random feed-in, including parts not required). For the feed-in, a simple buffer in the form of a queuing model was used that is operated similarly to the FIFO principle. One hundred simulation runs were calculated for each of the $6 \times 7 \times 2$ combinations of factor steps. Given the high amount of computing time required, the simulations were performed on the RZ cluster in the computer centre at RWTH Aachen.

The simulation results show that the target product was correctly assembled in all 8400 simulation runs. No assembly errors or blocking ("deadlocks") of the cognitive processor occurred.

The CCU processing time and the number of assembly cycles for the random feed-in of the parts are shown in Fig. 5. If we first consider only the time required, we can see that the processing time increases when more parts are used in the target object (Fig. 5, left). However, looking at the number of parts on the queue at the same time, it is surprising to note that processing time decreases as the number of

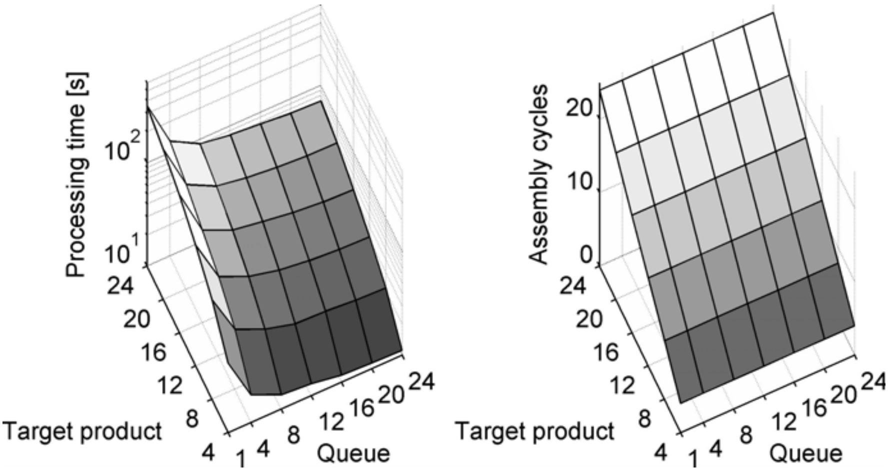


Fig. 5 CCU processing time (*left*) and number of assembly cycles required (*right*) as a function of the size of the target product and the number of parts fed in on the queue in random feed-in

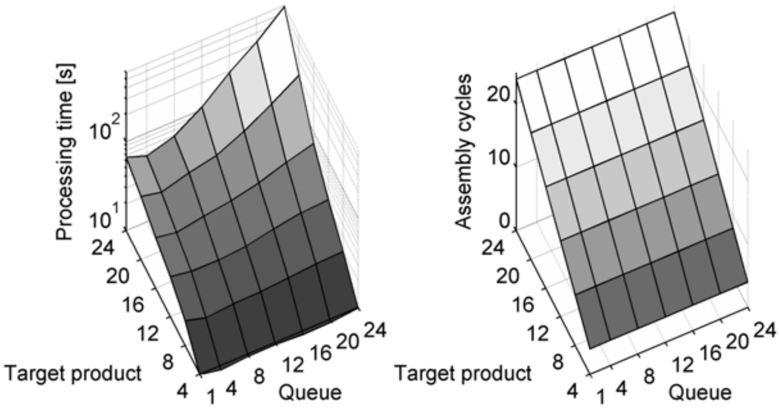


Fig. 6 CCU processing time (*left*) and number of assembly cycles required (*right*) as a function of the size of the target product and the number of parts fed in on the queue in deterministic feed-in

parts increases. If we consider the number of simulated assembly cycles for a target product of a given size and for feed-in with given parts, we see that the anticipated number of assembly cycles is obtained (Fig. 5, right).

The corresponding results for the deterministic feed-in of parts are shown in Fig. 6. The simulation results clearly show a disproportionate increase in processing time as the size of the target product and the number of parts on the queue increase (Fig. 6, left). The number of assembly cycles, on the other hand, behaves as expected in relation to the size of the target product (Fig. 6, right).

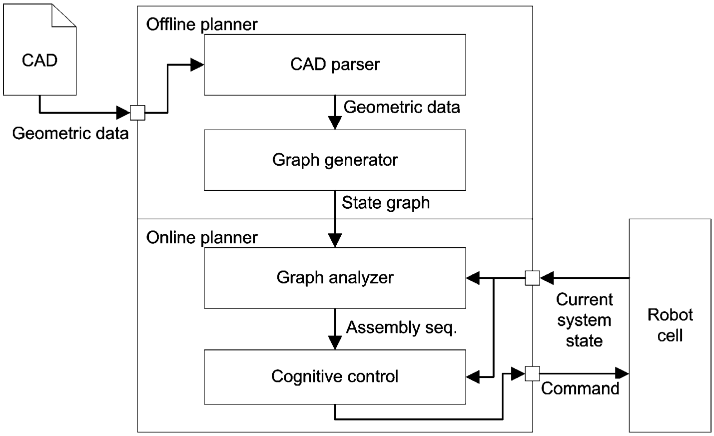


Fig. 7 Hybrid plan of the assembly planner

The results of the simulation study show that a CCU based on SOAR cognitive architecture is able to reliably perform assembly planning. In the given application, SOAR proves to be particularly suitable for reactive planning under the boundary condition of random feed-in of parts. In the case of deterministic feed-in, however, the study showed exponential run-time behaviour. Although difficult to understand intuitively, this simulation result can be explained by the way SOAR functions during the decision-making process. It compares each required part on the queue with every possible position within the target product. These comparisons result in "proposals" that provide the basis for decisions on executing action primitives. Due to the combinatorics, this can lead to a non-polynomial increase in run-time behaviour (e.g. [Bar90]).

If we want to achieve dynamic system adaptation to changing boundary conditions using – instead of SOAR – generic planning algorithms such as the Fast-Forward Planner [Hof01], the only way to do so is by performing continuous re-planning or by completely forward planning all possible sequences of fed-in parts. Complete forward planning for products comprising just 15 parts would require drawing up over 3.6 billion plans. Forward planning can therefore no longer be controlled in normal cases by combinatorics. Continuous re-planning during assembly is also not possible, since combinatorics cannot satisfy the real-time demands for comparable reasons. By contrast, the concept presented in this paper of a CCU based on SOAR meets the demand for dynamic system adaptation very well, as the simulation results for random feed-in clearly show. However, the results also show that, unlike generic planning algorithms, the CCU has only limited suitability for classic deterministic planning tasks. The study observed, for example, exponential run-time behaviour with a strictly deterministic feed-in of required parts.

For this reason, a more advanced hybrid solution was developed (see Fig. 7). It involves making a distinction between an "offline planner", which computes com-

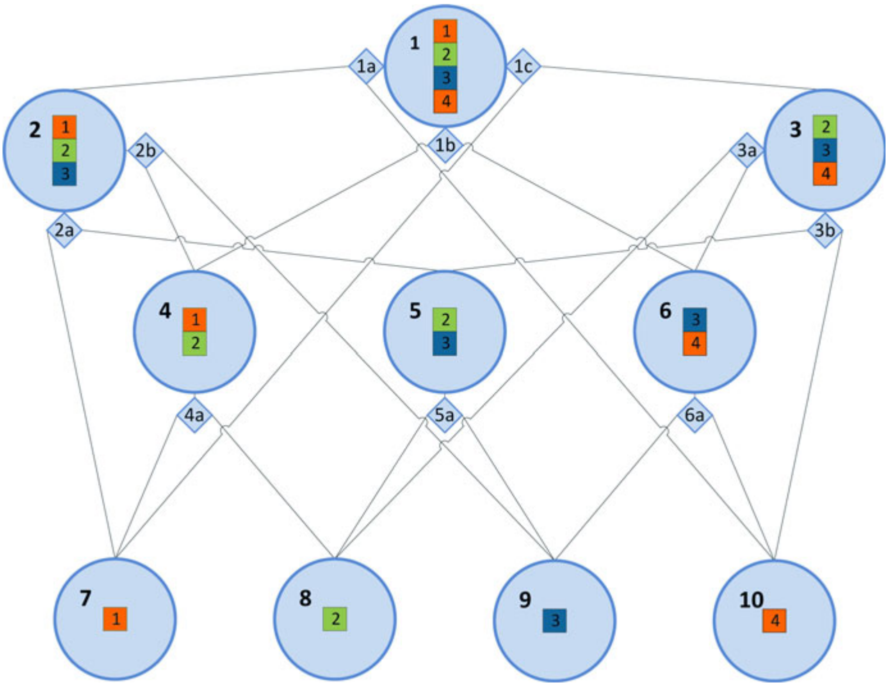


Fig. 8 And/or graph for a tower of bricks

plex planning steps based on geometric analyses prior to assembly, and an "online planner", which uses the results of the offline planner to generate assembly plans during the assembly process, depending on the current situation.

The offline planner consists of two components: the CAD parser and the graph generator. The parser receives the CAD description of the product to be manufactured and extracts from this the geometric information on the whole product and the individual components. This information is then forwarded to the graph generator. The generator follows an "assembly-by-disassembly" strategy [LC93] to generate all the expedient assembly sequences for the given product. This involves starting from the fully assembled state and generating all possible disassembly steps recursively, until there is nothing but individual components. Read backwards, these disassembly steps show all the possible assembly sequences. The graph generator performs this process using the method presented by Thomas (2008) [Tho08]. The system examines pairs of all subsets of components to establish whether these can be separated from each other, collision-free. Invalid disassembly steps are rejected, while valid steps are added to an and/or graph [HdMS86] and further examined and evaluated on the basis of various criteria. An and/or graph for a simple tower made of four bricks is shown in Fig. 8.

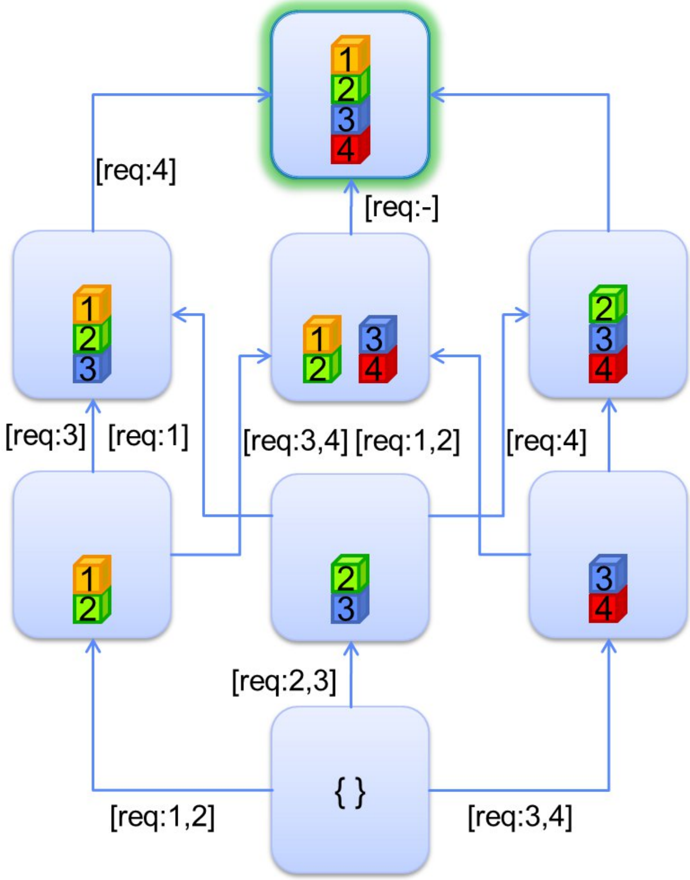


Fig. 9 State graph produced from the and/or graph

Each hyperedge of the and/or graph represents one disassembly action, or, in the opposite direction, one assembly action. As some assembly actions have to be performed by different tools or by a person, different costs depending on the type of action are assigned as vectors to each hyperedge. The finished and/or graph is then transformed into a state graph (see Fig. 9) because the online planner uses a process – similar to those applied in assistant systems [ZW08] – that cannot be used for hyperedges.

During the transformation, each hyperedge is converted into a simple edge. The corresponding nodes, which represent the resulting disassembly steps, are merged into one node: if both nodes consist of more than one individual component, a new node is generated that contains both sub-products. If a node contains only one component, this node is removed and the respective component is added to the new edge as a requirement. The resulting state graph is then transferred to the online planner so that assembly can begin.

Within each assembly cycle, the current system state is transmitted to the online planner during assembly, the next action to be performed is calculated, and the robot cell is activated accordingly. Decision-making is carried out by three components: the graph analyzer, the paralleliser and the cognitive control (CC). The graph analyzer contains the system state and updates the state graph. First, the current state of the assembly cell is located in the diagram. Then all the following edges are updated. Edges whose required components are not contained in the current state receive additional "penalty costs". Edges further from the node describing the current state are assigned lower costs. The online planner thus gains the ability to speculate. Actions that are not possible at present, because the corresponding components are not available, are more likely to be integrated into a plan the further they lie in the future. The algorithm "hopes" that the required component will be delivered before it is required.

After updating the state graph, the least expensive path – according to the given target system – from the current state to the target node is calculated using the A* algorithm [HNR68]. When passing through the graph, A* selects as the next node to be examined the node x, for which the function $f(x) = h(x) + g(x)$ is minimal. The function $g(x)$ designates the costs of the path to be taken to arrive at node x. In addition to the costs of the individual edges of the graph, the cost calculation also takes into account any necessary tool changes. In view of prevailing safety regulations, higher costs are allocated to changes between robots and humans than to changes between tools. Paths with fewer changes therefore have lower costs. The function $h(x)$ is a heuristic which estimates the proximity of a node to the target node. The heuristic employed here uses the number of components already correctly assembled and the valuation assigned by the offline planner with respect to machine transparency. The path calculated in this way is passed on to the next component as the plan to be followed. The process described ensures that this is an optimal plan with respect to several criteria:

- High penalty costs for actions that cannot be carried out ensure that the online planner selects the most realistically probable assembly sequence.
- Additional costs for tool changes create a preference for choosing sequences where the same tool is used for longer periods or which can be carried out by a single human operator.
- Reductions in penalty costs for assembly steps that cannot be carried out, depending on their distance from the current state, create a preference for assembly sequences that can be started immediately, because actions that cannot be carried out are shifted to the end.

A further optimisation step to accelerate assembly is performed in the paralleliser component. The fixed sequence of assembly actions received is examined for actions that can be carried out in parallel. The sequence is thereby seen as a sequence of sets of assembly actions. Each of the sets is examined as to whether it can be carried

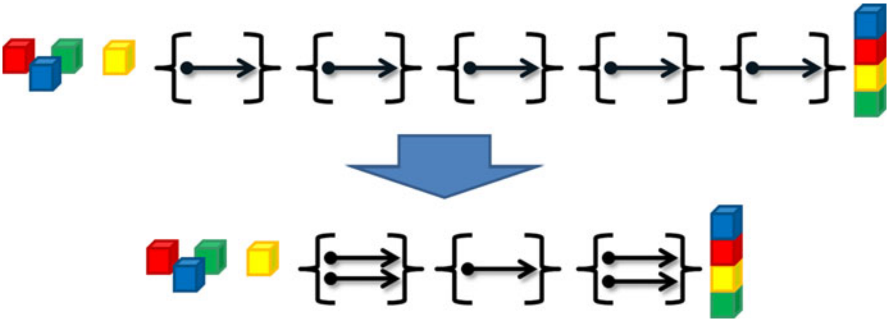


Fig. 10 Assembly plan as a sequence of sets of assembly actions – before and after parallelisation

out in parallel to the following set, i.e. whether all elements of both sets can be carried out in pairs at the same time. This parallelisation can be derived from the and/or graph: two actions, x and y, can be carried out exactly in parallel when their corresponding hyperedges – e_x and e_y – have a common predecessor hyperedge and when neither e_x nor e_y is a predecessor of the other. If two sets can be carried out in parallel, they are joined and examined to see whether they can be carried out in parallel with the next set. The result of this process is a sequence of sets of assembly actions (Fig. 10) which is then transferred to the decision-making component, the CC (Fig. 7).

Transferring a plan as sets of actions that can be performed in parallel has a number of advantages. On the one hand, assembly can be accelerated because several robots or even the human operator can work on the assembly at the same time. On the other hand, the CC has greater freedom for decisions because it is free to select the sequence in which the actions within a set are to be processed (if they cannot be performed in parallel).

As already mentioned, the CCU is based on SOAR, a cognitive architecture which attempts to simulate the human decision-taking process. The schematic sequence within this component is shown in Fig. 11. During assembly, the CC receives the current system state, transmits it to the online planner and receives back the assembly plan described above. On the basis of this plan and the current state, a decision on the next action is taken using the stored rule base. The CC can decide to follow the given assembly plan and to execute a suitable action from the first set of actions at its own preference. Alternatively, it can decide to ask the human operator for assistance, or to wait until the situation changes, for example through a new component being fed in. After executing the respective action, the resulting system state is queried and checked. If it corresponds to the target state, i.e. it contains the finished product, the assembly process ends. Otherwise the system examines whether the state has changed purely as expected, i.e. as a result of the action performed. If this is the case, it continues processing the assembly plan already received. If the situation has changed unexpectedly, the CC initiates re-planning by the online planner.

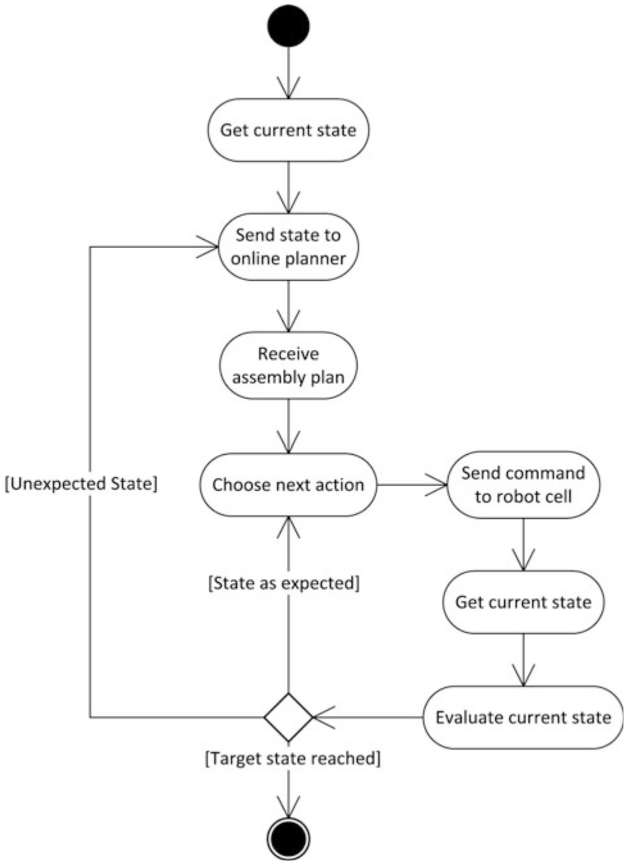


Fig. 11 Sequence of information processing in the CCU

4.3 Prototype Realisation of a Cognitively Automated Assembly Cell

To test and develop a CCU in a near-reality production environment in a variety of different assembly operations, a robotic assembly cell was set up [BKH08]. The layout of this cell is shown in Fig. 12. The scenario was selected to comprise major aspects of an industrial application (relevance), and at the same time to easily illustrate the potential of a cognitive control system (transparency).

The main function of the demonstrator cell is the assembly of known objects. Part of the cell is made up of a circulating conveyor system comprising six individually controllable linear belt sections. Several photoelectric sensors are arranged along the conveyor route for detection of components. Furthermore, two switches allow components to be diverted onto and from the conveyor route. Two robots are provided for handling the components, with one robot travelling on a linear axis and carry-

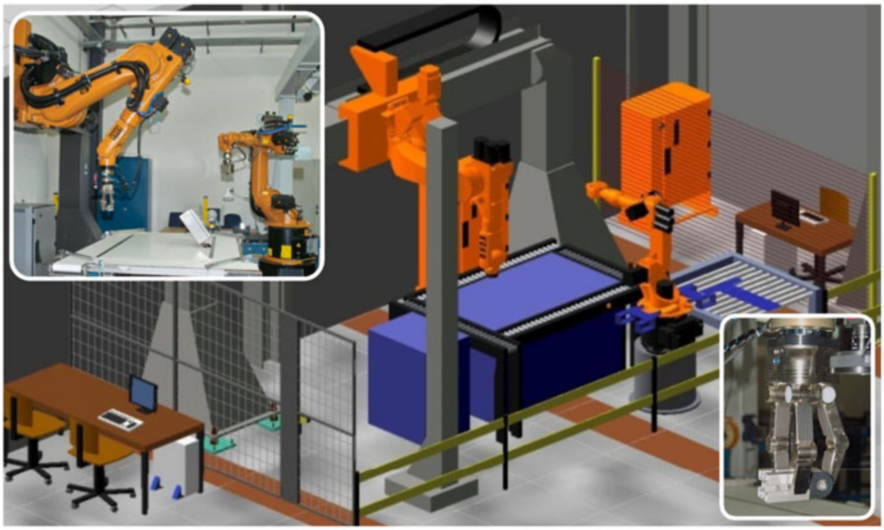


Fig. 12 Layout of the assembly cell

ing a tool (a flexible multi-finger gripper) and a colour camera. Several areas were provided alongside the conveyor for demand-driven storage of components and as a defined location for the assembly (see Fig. 13). One area is provided for possible preliminary work by a human operator. This is currently separated from the working area by an optical safety barrier. The workstation has a multimodal human-machine interface that displays process information ergonomically, allowing it to provide information on the system state and to help solve problems, if necessary. Detailed information on the configuration of the multimodal interface can be found in, for example, Odenthal et al. [OMGS08, OMK+09], and in Schlick et al. [SOM+09]. To simultaneously achieve a high level of transparency, variability and scalability in an (approximate) abstraction of the actual assembly process, building an assembly of LEGO Duplo bricks was selected as the assembly task. To take into account the criterion of flexibility for changing boundary conditions, the bricks are delivered at random (see Sect. 4.2). In terms of automation components, the system consists of two robot controllers, a motion controller and a higher-ranking sequencer. The latter takes the form of a CCU.

The initial state provides for a random delivery of required and non-required components on a pallet. One of the robots successively places the components onto the conveyor. The automatic-control task now consists in coordinating and executing the material flow, using all the technical components, in such a way that only the assembled product is on the assembly table at the end. As has already been explained, the automatic generation of valid assembly sequences, e.g. directly from a CAD model, is an extremely complex problem for which a universal solution has still to be found. In the present case, however, it is possible to find valid sequences with reasonable computing time that can be generated using the hybrid planning

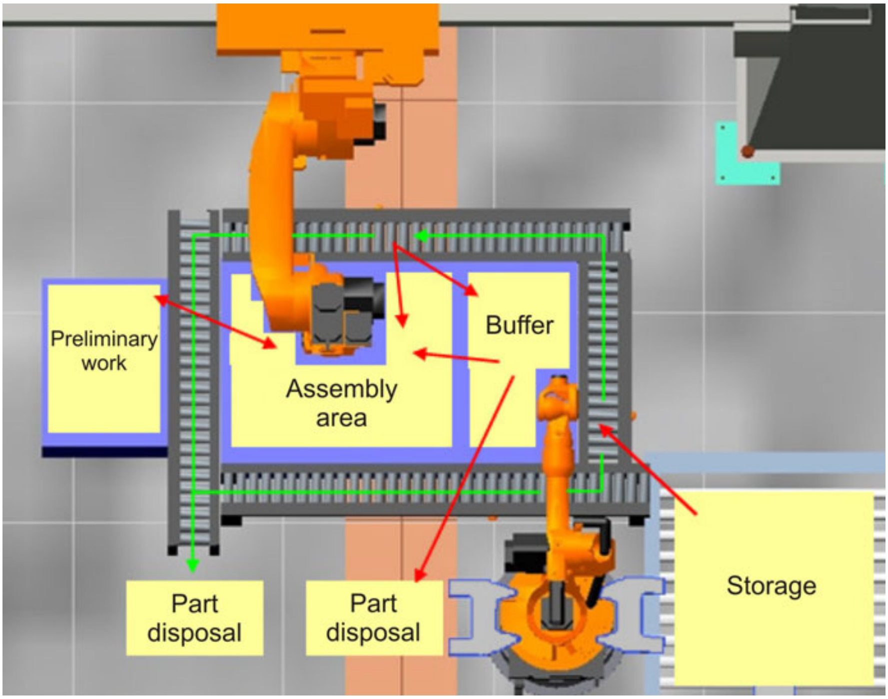


Fig. 13 Assembly and storage areas in the assembly cell

process from Sect. 4.2. The result of this kind of upstream planning process is a set of sequences extracted from an assembly priority graph that serve the dispatcher as inputs. The assembly planner described in Sect. 4.2 is also involved in solving the assembly problem. Even for an assembly problem of average complexity, a number of additional boundary conditions have to be observed when planning the assembly graph in order to arrive at a valid assembly sequence. Such limitations exist particularly in the following basic operators, which are based on the MTM-1 taxonomy ([DNTHM06]; see Sect. 4.5):

- REACH: Does the assembly situation, in combination with the gripper geometry, permit a valid approach trajectory?
- GRASP: Does the assembly situation, in combination with the gripper geometry, make it possible to grip the component during positioning (joining) (see Fig. 14, left)?
- POSITION: Does the assembly situation permit movement in joining direction (see Fig. 14, centre)? Does the assembly situation permit a stable force couple between the component to be positioned/joined and the assembly (see Fig. 14, right)?

The necessary call parameters have to be provided for commanding the functional units via the device interface. Important poses within the cell are preconfig-

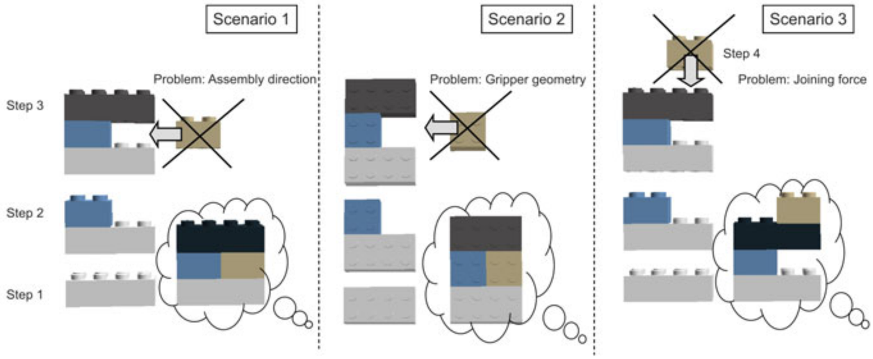


Fig. 14 Boundary conditions in positioning the demonstrator components

ured and are processed within the coordination layer. However, the exact target pose might only emerge at run-time, when a position is located on the pallet, for example. Operation always takes place in a discrete problem space. A component can be deposited on the pallet in, e.g. a given pattern that is stored as part of the plant model. The executor now supplies a discretised frame that corresponds to an actual (relative) component pose and has to be scaled to the modelled grid and offset against the reference pose. All the executors use this principle. Corresponding discretised poses are:

- Depositing poses of components or assemblies (in the cell coordinate system)
- Joining poses of components in the assembly (in the assembly coordinate system)
- Gripping poses on components (in the component coordinate system)

Frame and transformation operations are used to calculate the resulting target pose. This makes it possible to easily calculate random links between different coordinate systems (see Fig. 15).

Atomic commands are used in the technical layer to control the robots, grippers, conveyor belts and switches. The challenge here lies in linking the PC-based cognitive controller to the industrial device controllers.

Before a plant can begin production, it must be sufficiently tested. The advantages of using virtual commissioning for this purpose are increasingly being recognised. A cognitive control system probably has even greater need of simulative testing than a classic system does. This is because system behaviour in this case is not even known "on paper" – according to the requirement, it is not generated until runtime. First the question has to be answered as to how a control framework can make it possible to test the resulting processes in advance and – if possible – to visualise them. One possibility is by using a simulation tool of the kind used in connection with classic commissioning. These kinds of simulation tools generally have an OPC interface that allows them to connect to an external controller (generally in the form of a soft PLC). To avoid having to create several interfaces in the cognitive controller to device controllers and simulation systems, an abstracted interface was used that

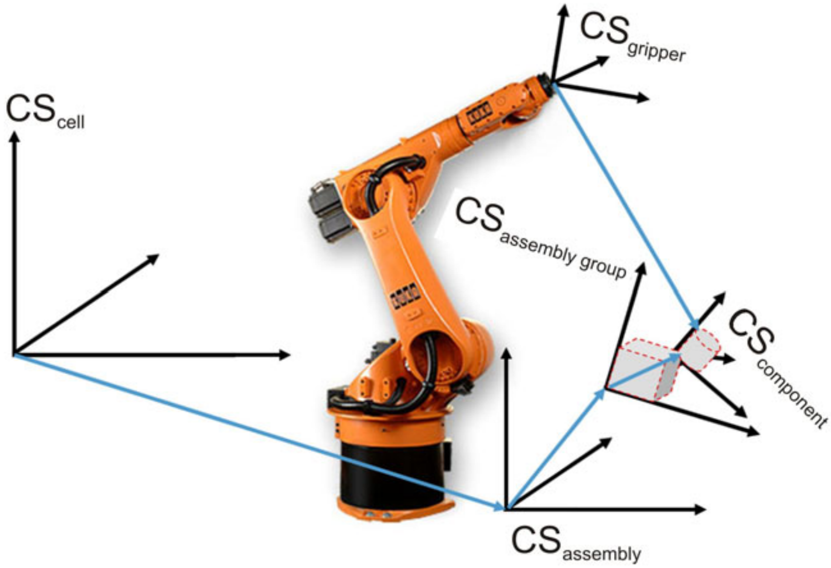


Fig. 15 Coordinate systems and transformations

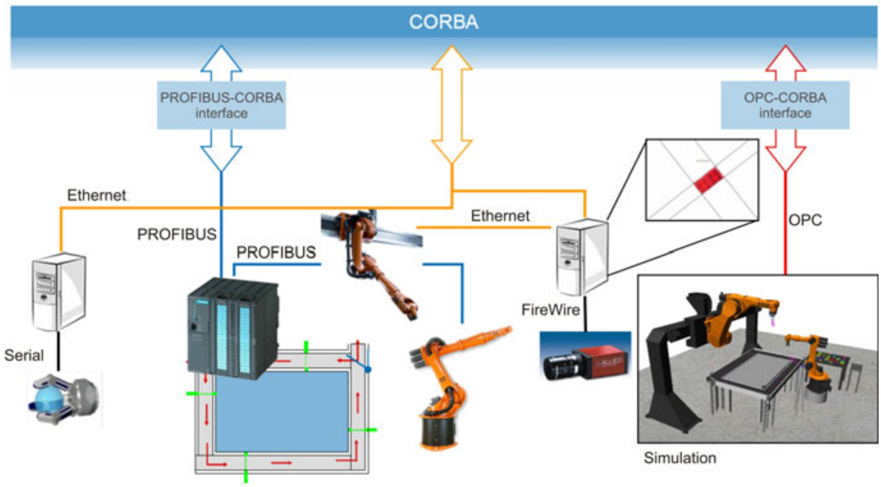


Fig. 16 Communication structure in the technical layer

allows the different types of device controller and simulation software to be linked transparently. This abstracted interface communicates using the real-time-capable CORBA middleware (see Fig. 16).

In the technical layer, the function calls of the actuators and sensors with their parameters as control commands are either transmitted directly via the CORBA interface from the cognitive controller to the corresponding PC-based controller, or they are transferred to the fieldbus by a PC-based interface with a corresponding CORBA call. In the demonstrator cell, the following technical sub-systems are controlled via a PROFIBUS interface:

- Two KR C2 robot controllers made by KUKA
- One SIMOTION motion-control system made by Siemens
- Further actuators (two-jaw gripper, pneumatic switches) and sensors (photoelectric sensors) can also be reached as I/O systems via the PROFIBUS. These systems are linked to the cognitive controller via a CORBA PROFIBUS interface.

The following are linked directly via CORBA:

- An image processing system for identifying the individual components and detecting their position
- A gripper system for a flexible gripper, made by Schunk, with seven degrees of freedom.

As the components have to be detected and gripped even when the conveyor belt is running, the robot must track them at a speed synchronous with that of the conveyor during the detection and gripping process. To achieve this, a direct control loop between robot controller and image processing system was created. At the technical level, the loop uses the KUKA RSI real-time interface to manipulate robot movements in the interpolation cycle. In the layer model, image processing in the control loop is located in the reactive layer due to its real-time character.

A truism for every production system is that a plant behaves correctly when it is appropriately designed, and using a cognitive control system does nothing to change this simple fact. However, the example of the demonstrator cell shows that the behaviour achieved with a correct model and self-optimisation completely met the expectations in every case (KEMPF 2010). The duration of the process and the number of operations necessary depends to a large degree on the modelling and can be greatly influenced with just a few rules. Further factors are random influences – in this case the random feed-in of components, and non-deterministic decision-making within the SOAR agents. Figure 17 shows how the duration of an assembly process is affected by random influences alone.

Due to the semi-decidability of some planning tasks, no hard real-time behaviour can be expected from a cognitive controller at the planning level. Nevertheless, the run-time behaviour should still satisfy certain boundary conditions, particularly in the reactive layer.

As a rule, both the temporal behaviour and the necessary memory requirement are dominated almost exclusively by SOAR (planning processes are one exception; the planning module is responsible for these). The following times were measured on a normal desktop PC with a 2.5 GHz dual-core processor and 2 GB RAM. The control architecture means that there is only one control cycle that covers the planning, coordination and reactive layers. For the measurement of the cycle time it

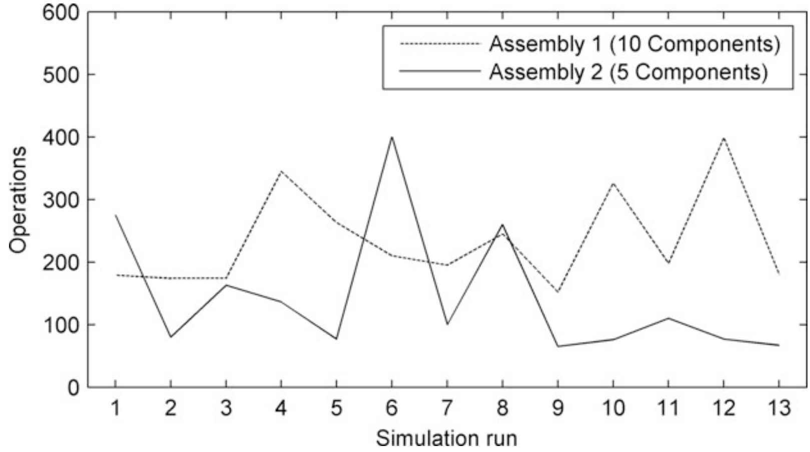


Fig. 17 Number of operations necessary for two parallel assembly operations

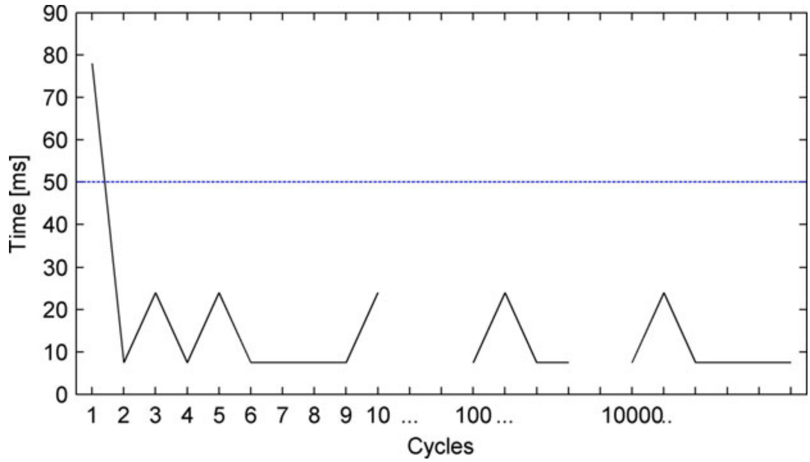


Fig. 18 Controller stability and cycle duration compared with normal industrial reaction time (50 ms)

should be noted that the time resolution of the standard operating system (Windows XP) on the platform used was approx. 15 ms. To obtain a more precise statistical mean value, the total run-time was therefore divided by the number of necessary control cycles. It emerged, however, that the actual cycle time varied only very slightly from this mean value. This is also to be expected, because each SOAR agent usually performs exactly one decision cycle per control cycle.

If a normal industrial reaction time of 50 ms is assumed (see Fig. 18), the cognitive control system implemented always reacts within this period of time. The coordination and reactive layers thus initially fulfil the speed demands of a suitable controller for the demonstration cell.

The current results are aimed solely at designing the technical “components” in the complex human-machine system of a cognitively automated assembly cell. From a purely technical point of view, the results demonstrated that robot-supported assembly processes can be cognitively automated, even though, with regard to planning, a hybrid approach had to be developed that combined classic planning elements with reactive, cognitive planning to meet the demands placed on reactive and adaptive planning.

Building on this, the following sections will focus on the human being in the overall system, and will examine how humans and the technical sub-systems interact.

4.4 Process Logic for a Cognitively Automated Assembly

As explained in Sect. 2.3, cognitive automation shifts the spectrum of tasks for the human being. Parts of the planning that originally lay in the human sphere of responsibility, because they involve the step-by-step transformation of a manufacturing strategy into an RC program, can be taken over by the cognitive control unit. This can lead to the abovementioned incompatibility between the human mental model and the process knowledge stored in the technical system. With the human and the machine, the working system has two totally different information-processing “systems”, which either encode and process sub-symbolically as with the human, or merely have symbolically encoded information on the production process as with the machine (Fig. 2).

The work presented below aims to avoid such incompatibilities by developing a cognitive-ergonomic model of the process knowledge. The idea is to adapt the process knowledge stored in the cognitive control unit to human thought patterns, and to influence the behaviour of the cognitive system in such a way that humans can easily understand and reliably anticipate it.

Elementary components of the MTM-1 taxonomy were used for the cognitive-ergonomic design of the process logic for controlling the assembly robots. The hypothesis is that a sequence consisting of empirically validated basic elements/movements that conform to expectations can be quickly learned and, if necessary, optimised by humans, even if the executing instance is a robot gripper arm [GRWK07, TSB+04]. The MTM components transformed into production rules, or SOAR operators, are equal and therefore not defined in a sequence. They correspond to the MTM-1 basic movements REACH, GRASP, MOVE (with integrated TURN), POSITION and RELEASE (see Sect. 4.3) that are used to control the robots in the cell. In addition, further rules are stored which, depending on the basic elements used, contain the physical boundary conditions (e.g. joining direction or conditions for positioning an element) and assess whether a fed-in element can be directly fitted or has to be stored in a buffer until a later assembly step.

As the research work focuses on evaluating the concept – not on optimising the process purely in terms of time – no tabular time information is stored initially.

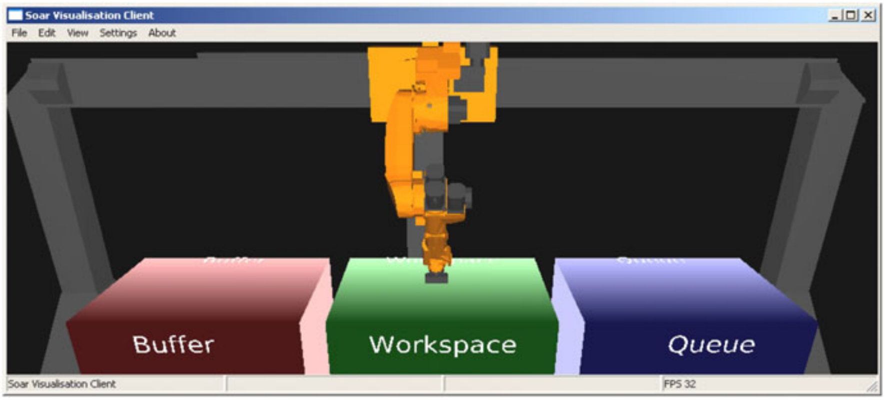


Fig. 19 The simulation environment

This simplification is acceptable if all the bricks necessary for the assembly are available or if the component is made of identical bricks, since with fixed starting and finishing positions of the end effector, the sum of the paths and hence the overall time does not change, despite different assembly sequences.

A prototype implementation of the CCU described is carried out in a self-developed simulation environment, very similar to that of the assembly cell. For simplification, the conveyor belt was replaced by a panel similar to a chess board. The fed-in bricks are laid out on the panel's fields. The supply process can be varied from randomly feeding in a single brick through to delivering all the necessary bricks. The simulation included the workstation and buffer areas as independent areas. Regarding the simulation of the gripper, it is assumed that the geometry of the gripper means there are no restrictions in approaching or joining the elements. The prototype simulation environment is shown in Fig. 19.

The prototype implementation of the CCU in the simulation environment should be considered as a reference model. The reference model was validated using several easy-to-assemble geometric objects made up of LEGO bricks. The objects differed in the number of bricks used, in colour and in shape (e.g. pyramid, cube, flat surface). The assembly results of a pyramid consisting of 30 identical bricks is explained here as an example. Identical bricks were chosen because this meant that each component could be installed in any position within the pyramid, thus resulting in a large number of possibilities ($\sim 10^{25}$) for the assembly sequence.

Without further defining the spatial dimensions within the workspace of the assembly cell, an assembly sequence like the one shown as an excerpt in Table 1 is expected. If we understand one complete cycle as running from the beginning of a REACH operator until the end of a RELEASE operator, we expect the number of cycles to be 30.

Repeated simulation runs ($n = 1000$) with pre-picked sets of parts (all the necessary bricks were available) and with a random supply of parts (including bricks not required) show that the desired target object is always built, error-free and in the

Table 1 Expected process sequence based on the MTM-1 taxonomy

	Step 1	Step 2	Step 3	Step 4	Step 5
Brick 1	Reach Start → Panel	Grip Brick 1	Move Box → Pos. 1	Position on Pos. 1	Release
Brick 2	Reach Pos. 1 → Panel	Grip Brick 2	Move Box → Pos. 2	Position on Pos. 2	Release
Brick 3	Reach Pos. 2 → Panel	Grip Brick 3	Move Box → Pos. 3	Position on Pos. 3	Release
...					

expected number of complete cycles. Given the simplified treatment of the gripper, no deadlocks occurred. This therefore replicated the simulation results presented in Sect. 4.2. It should be pointed out here, however, that the variance in the observable assembly sequences is immense, meaning that despite the use of an anthropocentric taxonomy in the form of MTM-1, the question arises as to whether the described approach is sufficient to ensure that system behaviour conforms to the expectations of the assembly cell user.

This question must be considered from different perspectives. If we look at the sequence of operators (from REACH to RELEASE) within a single cycle, the sequence conforms to expectations because it corresponds to the normal cycle of movements of the human hand/arm system. This does not apply, however, to the sequence of cycles, or assembly sequences. With SOAR these prove to be a statistical succession of possible sub-steps that is impossible for humans to understand because it happens with no recognisable heuristics.

From a technocentric point of view, the reference model provides valid results in the sense of a complete, error-free and expedient structure. From an anthropocentric perspective, however, the results appear to be inadequate since the high procedural variance means that they cannot be compatible with human expectations. Marshall's Schema Model [Mar08] divides the types of knowledge for the human decision-taking process into four categories: 1) Identification knowledge (*What is happening at the moment?*); 2) Elaboration knowledge (*What has high priority and why?*); 3) Planning knowledge (*What has to be done and when?*); 4) Execution knowledge (*Who should do what?*). Regarding the discrepancy between the technocentric and anthropocentric approach, Mayer et al. [MOF+09] conclude that the reference model significantly under-represents elaboration knowledge.

To examine the hypothesis that a stronger focus on elaboration knowledge will have a positive impact on the expectation conformity of the system behaviour, a series of experiments investigating assembly strategies was held under laboratory conditions and with 16 participants (13 male, 3 female). The participants had to assemble a complete assembly on the basis of a CAD drawing. To keep the results comparable with the assembly cell, limitations were imposed on the execution of the task. Participants were only permitted to use one hand for the assembly, and were not allowed to build sub-groups or pick up several bricks at once. The target object was a single-coloured pyramid of 30 LEGO bricks.

The analysis of the assembly strategies in the experiments produced three general rules:

- Rule 1: From the viewpoint of the participant, the first brick to be assembled is located in one of the left corner positions (87.5 % of the sample cases).
- Rule 2: Preference is given to selecting bricks that can be positioned directly next to an adjacent brick during assembly (81 %). This will be referred to as compliance with the adjacency relationship.
- Rule 3: The target object is built up in layers that lie parallel to the assembly surface (81 %).

4.4.1 Validity of the Collected Data with Respect to the Defined Rules

A further series of experiments (ES2) was carried out to check the validity of the previously identified assembly rules. The series involved 25 people (14 male, 11 female) who are not involved in manual assembly during their day-to-day work. The subjects are therefore not classified as experienced workers in the sense of the MTM taxonomy. None of the participants had taken part in the first series (ES1). The average age was 26.9 years (SD = 3.4). For ES2 the task from ES1 was expanded to require the subjects to assemble ten identical pyramids in succession in a timely manner. This meant that, in spite of the laboratory conditions, the subjects gained a degree of experience that is quite comparable with that of small-series production. The reason for the expansion of the task was to avoid "unusual" methods of working due to the simple task. Subjects had to signal the start and end of each assembly sequence by double-clicking a pushbutton switch installed in the assembly area. The assembly process was subject to the same limitations as in ES1 – one-handed assembly and no building sub-groups or gripping several bricks at once.

If the rules identified from ES1 are also applicable to ES2, at least equal relative frequency f_i for each individual rule should be recognisable in the empirical data. On the basis of this assumption, the following hypotheses can be formulated for the statistical test:

- H_1: The relative frequency of the position of the first brick in ES2 (f_{h2_Rule1}) is higher than the frequency in ES1 (f_{h1_Rule1}), or:
- $H_{01} : f_{h2\_\text{Rule1}} = f_{h1\_\text{Rule1}}$.
- H_2: In ES2, assembly that conforms to the adjacency relationship (f_{h2_Rule2}) occurs with a higher relative frequency than in ES1 (f_{h1_Rule2}), or:
- $H_{02} : f_{h2\_\text{Rule2}} = f_{h1\_\text{Rule2}}$.
- H_3: Assembly in layers in ES2 (f_{h2_Rule3}) occurs with a higher relative frequency than in ES1 (f_{h1_Rule3}), or:
- $H_{03} : f_{h2\_\text{Rule3}} = f_{h1\_\text{Rule3}}$.

To verify the null hypotheses, the χ^2 goodness-of-fit test is applied with a significance level of $\alpha = 0.05$.

Table 2 Results of the χ^2 goodness-of-fit test

	MV ES2 (EV ES1)	d*f*	χ^2	*p*
ES2, Rule 1	80.4 % (87.5 %)	1	11.52	.00
ES2, Rule 2	91.2 % (81 %)	1	16.25	.00
ES2, Rule 3	97.2 % (81 %)	1	41.75	.00

$\alpha = 0.05$, MV: Mean value, EV: Expected value,
ES: Experiment series

The results of the χ^2 test for H_{01} (position of the first brick in left-hand corners) are shown in Table 2. This clearly shows that H_{01} has to be rejected. With a relative frequency of 80.4 %, the observed distribution deviates significantly from that observed in ES1.

The results of the χ^2 test for H_{02} (taking account of adjacency relationships during assembly) are also shown in Table 2. The null hypothesis must also be rejected in this case. However, because the relative frequency of 91.2 % is higher than the expected value from ES1 (81 %), it can be said that the rule is followed more strictly than expected.

Finally, the results of the χ^2 test for H_{03} (assembly in layers) are also shown in Table 2. This null hypothesis must also be rejected. As the observed relative frequency is 97.2 % (expected value from ES1: 81 %), it is clear that this rule is also followed more strictly than expected.

4.4.2 Influence of the Rules on Prediction Quality

As already shown, the null hypotheses regarding the rules identified in ES1 had to be rejected. The results of the χ^2 goodness-of-fit test for the rules relating to compliance with adjacency relationships and to assembly in layers show that these are followed more strictly than expected. The only rule that could not be applied to the results of ES2 was the one relating to the position of the first brick. Nevertheless, in view of the relatively high satisfaction of the rule (80.4 %), it will continue to be considered in the further course of the study.

Finally, we also wanted to investigate how the identified rules – individually and in combination – influence the CCU's prediction accuracy regarding assembly steps preferred by humans, and the generalisability of assembly steps carried out by humans. To do so, independent sets of rules, which consist of the rules of the reference model and the respective auxiliary rule, are transferred to the CCU and simulated several times in a simulation environment developed especially for the experiments. The resulting data give an indication of how each set of rules influences the prediction accuracy of the simulation, i.e. its ability to predict the next step in the human assembly activity, and provide information on the generalisability of the set of rules with respect to ES2.

Table 3 Overview of the simulation models compared in the study

	MTM-1 rules	Rule 1	Rule 2	Rule 3
Model 1	×			
Model 2	×	×		
Model 3	×		×	
Model 4	×			×
Model 5	×	×	×	
Model 6	×	×		×
Model 7	×		×	×
Model 8	×	×	×	×

The additional cognitive simulation models were systematically expanded to include the rules corresponding to the heuristics. An overview of the simulation models is shown in Table 3.

For space reasons, in what follows only one dependent variable is used for evaluating the simulation models. The variable is derived from the criteria provided in Langley et al. [LLR09] for evaluating cognitive architectures. This criterion is based on the "optimality" criterion and represents the simulation model's prediction quality regarding the assembly activity. The prediction quality of an observed model is defined as the probability of the simulation model positioning a given brick in conformity with the human action during simulated assembly. In other words, assuming a given state x_{i-1} and the stored process knowledge for reaching the next state x_i, the probability $p(x_i|x_{i-1})$ that this particularly state will be reached is evaluated. This observation is followed step-by-step for the assembly sequence until the target object is fully assembled.

As the simulated assembly is a Markov process, it is admissible to factor both the overall probability into the transition probabilities $p(x_i|x_{i-1})(2 \leq i \leq 30)$ described above, and the initial probability $p(x_1)$, where x_1 represents the initial state. The conditional probability of a sequence P_s is calculated as follows:

$$P_s = \prod_{i=2}^{30} p(x_i|x_{i-1}) * p(x_1). \tag{1}$$

The logarithmic probability was calculated to simplify the interpretation of the resulting data. The prediction quality is therefore operationalised using "logarithmic conditional probability" (LCP):

$$\mathrm{LCP} = \sum_{i=2}^{30} \log_{10} p(x_i|x_{i-1}) + \log_{10} p(x_1). \tag{2}$$

In Eq. (2), $p(x_i|x_{i-1})$ is the conditional probability that the observed simulation model assigns to a brick that was originally positioned by the human. Thus, the LCP values vary between 0 (perfect prediction) and $-\infty$ (absolutely wrong prediction or behaviour that the simulation model cannot validly reproduce).

Table 4 Mean values for the logarithmic conditional probability (LCP) for the simulation models examined

Simulation model	LCP
Model 1	−24.595
Model 2	−24.422
Model 3	−20.579
Model 4	−20.279
Model 5	−20.430
Model 6	−20.192
Model 7	−15.848
Model 8	−15.671

To examine the prediction quality of the different cognitive simulation models (see Table 3), the index of the simulation models is regarded as an independent variable. Expanding the reference model of the cognitive simulation (Model 1 in Table 3) is expected to increase the prediction quality when additional empirically identified rules are added to the knowledge base. The following null hypothesis is formulated on the basis of this expectation:

- H_{04}: The prediction quality of the cognitive simulation models exhibits no significant differences.

The Kruskal–Wallis test was used with a significance level of $\alpha = 0.05$ to test for differences in the prediction quality. This test can be regarded as a non-parametric form of the one-factor analysis of variance (ANOVA). This is necessary because the Lilliefors test for normal distribution rejects the normal distribution for all LCP values ($p < 0.01$ in each case). A post-hoc test with adaptations for multiple comparisons according to Bonferroni was also carried out.

4.4.3 Results

Table 4 shows the mean values for the dependent variable LCPs from Eq. (2), which describes the prediction quality for the 250 assembly sequences from the second empirical study.

On the basis of the simulation data underlying Table 4, it is clear that there is a significant difference ($p = 0.00$) in the LCP values. H_{04} must therefore be rejected. Figure 20 shows the simulation data as box plots of the observed cognitive simulation models. A higher LCP value means higher prediction quality with respect to human behaviour.

Post-hoc pair comparisons were carried out to determine the differences between the cognitive simulation models. Table 5 shows the significant differences ($\alpha = 0.05$) as a cross-reference table, where X represents a significant difference ($\alpha = 0.05$).

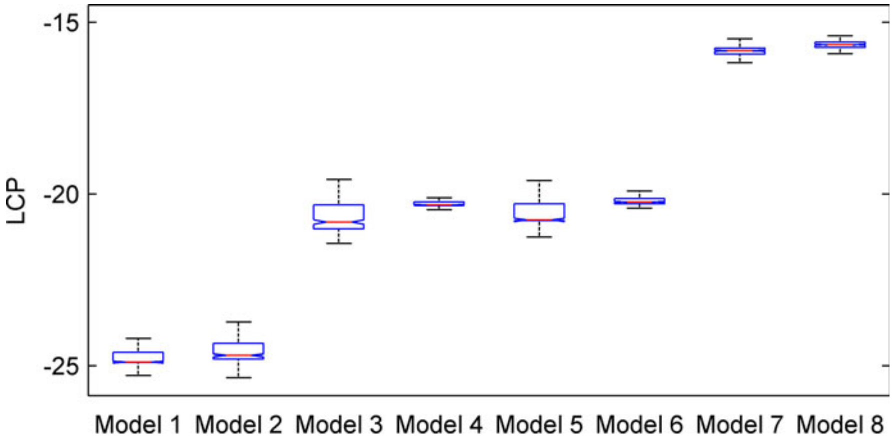


Fig. 20 Box plots of the logarithmic conditional probability (LCP) calculated for the simulation models examined

Table 5 Results of the multiple comparisons of the LCP values for the cognitive simulation models observed

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Model 1	–/–		×	×	×	×	×	×
Model 2		–/–	×	×	×	×	×	×
Model 3	×	×	–/–	×		×	×	×
Model 4	×	×	×	–/–	×		×	×
Model 5	×	×		×	–/–	×	×	×
Model 6	×	×	×		×	–/–	×	×
Model 7	×	×	×	×	×	×	–/–	
Model 8	×	×	×	×	×	×		–/–

If we compare all the cognitive simulation models, we can divide the models into three groups that are significantly different in terms of prediction quality. The first group has the poorest prediction quality and comprises Model 1 (the reference model for the cognitive simulation) and Model 2. Models 3, 4, 5 and 6 form the group with average prediction quality. Models 7 and 8 have the highest prediction quality.

The following conclusions can be drawn from the test results:

- Rule 1 has no significant effect when it is added to a cognitive simulation model.
- Rules 2 and 3 significantly influence the prediction quality of the cognitive simulation models, but they show significant differences in a direct comparison. Adding Rule 2 can improve the LCP value by between 16.32 % and 22.39 %. Rule 3 results in improvements ranging from 17.32 % to 23.29 %.
- The highest prediction quality is obtained when Rules 2 and 3 are combined. This increases quality by between 35.56 % and 35.83 %.

4.5 Human-Machine Interaction

As explained in Sect. 3, it is important to pay particular attention to the ergonomic design of the human-machine interface. Because the CCU can independently solve a certain class of rule-based production tasks, the human operator's duties mainly lie in cognitively demanding tasks. These include defining the production task, drafting rough process plans, defining the initial and boundary conditions and, in particular, monitoring the system state during the process and taking expedient action if disturbances or production errors arise. If the robot makes an assembly error, for example, the human operator must be able to quickly and efficiently intervene to enable system recovery. To achieve this, the sub-project designed, developed and evaluated a visualisation system that displays assembly information directly in the operator's field of view ("augmented reality", [OYN08]).

A laboratory study was carried out to examine this visualisation system from the point of view of software ergonomics and to analyse how the relevant information should be displayed for the human operator. The task used in the experiment assumes that a robot has implemented the scheduling of an assembly task previously defined by the operator. During processing, however, a fault has occurred that the cognitively automated system cannot identify and remedy independently. Possible causes of assembly errors can be "noisy" sensor data regarding component detection, and flaws in the fed-in components themselves. Two separate series of experiments were performed to investigate the "optimum" ergonomic display of the assembly information with respect to the time necessary for fault detection and the corresponding accuracy. Two different displays (a head-mounted display – HMD – for visualisation directly in the field of view, and a table-mounted display – TMD – for visualisation in the workspace) and various types of visualisation were compared.

4.5.1 Experiment Scenario and Implementation

Different modes of visual representation (and interaction) were drafted and developed for the ergonomic system design and evaluation. These modes are based on known methods for designing written manufacturing instructions and are derived from guidelines for technical writing [ABO03]. Exploded views and step-by-step instructions were used for ergonomically visualising assembly information in the field of view [OMGS08]. To display assembly information in high quality and to permit quick and precise error detection with minimal mental effort, the assembly objects were accurately modelled as 3D objects and their colour and contrast were adapted to provide an ergonomic display on the HMD. LEGO bricks, which are easy to describe, were selected as assembly objects (see Sect. 1).

Table 6 Technical data of the HMD and TMD

	HMD	TMD
Resolution	1280 × 1024	1280 × 1024
Image refresh rate	60 Hz	75 Hz
Monitor size	–	17″
See-through transmission	40 %	–
Weight	1.3 kg	7 kg
Brightness	max. 102.79 Cd/m^2	Typical 230 Cd/m^2; min. 197 Cd/m^2
Monocular FoV	60° diagonal / 100 %	–
Technology	LCOS	TFT
Manufacturer	NVIS	ELO

4.5.2 Experiment Design

The experiment design distinguishes between four factors. The first is "display type" (DT). The three other factors represent the different modes of presentation of the synthetic assembly information. These factors are: augmented vision mode (AVM); a priori presentation of the target state of the fully assembled assembly (APP); the mode for interactive decomposition and composition of the assembly during the error detection phase (DCM). These factors with the corresponding factor levels and the associated experimental conditions are explained below. Table 7 provides an overview of the factors and factor levels.

- DT: The visualisation systems were designed on the basis of two different display technologies: (1) A high-resolution HMD based on liquid-crystal-on-silicon technology (LCoS) with two half-silvered mirrors in front of the user's left and right eye for stereoscopic display; (2) A high-resolution TMD using TFT technology, as is common in German industry. The TMD was selected and adjusted so that it corresponded as closely as possible to the specifications for the HMD. The light intensity was set to 500 lux at the point of the real assembly object in the working area. The technical data of the two displays are given in Table 6.
- AVM: The position and orientation of the HMD can be measured in real-time using an optical infrared tracking system. This makes it possible to calculate the user's viewing direction and adapt the presentation of the virtual information in the field of view. Furthermore, the system can determine the position and orientation of the real assembly object in front of the user. This means that virtual information can be precisely superimposed onto the real object when the HMD is in use. No comparable visual superimposition is possible when using the TMD since it does not measure the position and orientation of the user's head. Only the orientation (rotation of the real model around the vertical axis) was measured in the real model and adapted in the virtual model (rotation of the virtual image by 20° around the vertical axis). Because generating a "perspective view" is technically complex due to the tracking system, a company can only justify acquiring

Table 7 The different factors and factor levels

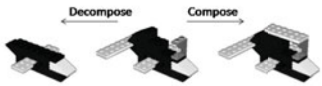
Factors	Characteristic	Examples
DT for augmented display	HMD	
	TMD	
AVM	Perspective view	
	Static view	
APP	Rotation	
	Assembly	
DCM	Step-by-step	
	Exploded view	

Fig. 21 Experiment configuration with turntable and HMD (*left*), experiment configuration with monitor (*right*), keypad for manipulating the virtual object (*top centre*), participant wearing the HMD (*bottom centre*)

this if this presentation mode significantly improves performance or reliability. For this reason, a simple static information display was also investigated. The two factors are therefore "perspective view" and "static view". In the perspective view, the display of the virtual assembly is adapted to the position and orientation of the real object and, when using the HMD, appears on the left at a distance of 4 cm from the real object. The position of the TMD was selected such that, as with the HMD, the virtual image appears to the left of the real model. The monitor was behind the turntable. This was intended to create as similar angle conditions as possible. In the static view, the virtual assembly is displayed in a fixed position relative to the monitor coordinates of the HMD or TMD. In the experiment the virtual object was displayed in the HMD, tilted at an angle of 20° to the vertical axis and in the third quadrant of the binocular display. In the TMD, the virtual object was displayed tilted at an angle of 20° to the vertical axis and in the centre of the monitor.

- APP: Before the actual error detection task, the subject was shown an a priori display of the target state (assembly). In this case a distinction was made between two factor levels: (1) Rotation: the complete assembly rotates 360° once, tilted at an angle of 20° to the vertical axis and at an angular velocity of 3.2 seconds; (2) Assembly: the virtual model is assembled virtually in steps with a cycle time of 1.2 seconds per sub-element.
- DCM: Two factors were analysed with respect to the mode for interactive manipulation of the LEGO model during the error detection process: (1) Step-by-step: the subject can independently compose and decompose the virtual model in steps, using two buttons on a keypad (see Fig. 21); (2) Exploded view: the subject can interactively explode or implode the virtual model using another button on the keypad.

Table 8 also shows the types of errors that are generally relevant to error detection. Because detecting a colour error is simpler than detecting a position error or an error in shape or number, the experiment does not investigate colour errors. Eight

Table 8 Possible error types

	Colour (not investigated)	Position (investigated)	Shape (investigated)	Number (investigated)	
Target state					
Actual state					

different tasks with similar degrees of difficulty were developed to analyse the remaining error types. Two tasks contained the error "Position", three tasks contained the error "Type/shape", and three tasks contained the error "Number".

4.5.3 Experiment Configuration

Figure 21 shows the main components of the visualisation systems that were used for the experiment. The LEGO model with the assembly error that had to be detected and identified was placed on the turntable, which was located on a conventional assembly bench in the participants' central field of view. Each person sat on a chair in a comfortable upright position during the experiment. The position and orientation of the HMD and the turntable were recorded with the smARTtrack real-time tracking system (made by ART GmbH). The participants used a coloured pen, which was located behind a transparent screen, to mark the incorrectly assembled LEGO brick. As soon as the person detected the error, he/she picked up the pen, which triggered a switch linked to the screen and recorded the time of the action. This point in time was taken as the moment of error detection for all participants. The keys for manipulating the virtual image were attached to a freely configurable keypad with the following key assignment: exploded view (left), decomposition/composition (top and bottom centre), repetition of the a priori presentation (right). The key at the top right has no function within this series of experiments.

4.5.4 Experiment Procedure

The laboratory studies for the HMD and TMD were performed separately, each with two groups of 24 participants. The same assemblies with identical errors were used in both studies. A full-factorial experiment design with measurement repetitions using three within-subject factors (AVM, APP, DCM) and one between-subject factor (DT) was selected. The task for the participants consisted of comparing the state of a real assembly object with the virtual representation on the screen (HMD, TMD) for possible errors. The experiment procedure was split into two main phases:

4.5.4.1 Pre-tests and Training Under Experiment Conditions

At the start of the study, general user data (age, profession, previous experience, etc.) were gathered using a questionnaire developed specifically for the study. Then the participants' visual acuity was recorded (tested in accordance with DIN 58220), as was their stereopsis and their colour vision (using the Ishiara colour test). Since wearing a HMD can quickly lead to visual fatigue and thus significantly influence factors like human performance and stress [PS07], participants' visual fatigue was recorded, based on Bangor (2000) [Ban00], using a questionnaire before and after performance of the task. Next, participants spent ten minutes practicing with the augmented vision system under the conditions that would be used in the experiment.

4.5.4.2 Data Collection

Each participant performed the following sequence eight times:

- Starting a run using APP of the target state of the LEGO model. The virtual sequence was presented in the participant's field of view, without him/her being able to see the real object.
- At the end of the initial presentation, the test supervisor fastened the real assembly object to a turntable. Participants could use the keys on the keypad to manipulate the virtual object. They could call up the a priori presentation at any time, but could not cancel the displayed assembly sequence. The participants' task was to compare the real object (actual state) with the virtual object (target state) for differences, without knowing whether and/or how many possible assembly errors the component contained. If they identified differences, they had to mark them with a coloured pen. Each component had one assembly error.
- Each participant then completed the questionnaire on visual fatigue.

The total experiment, including the pre-tests, lasted roughly two hours for each participant.

4.5.5 Participants

A total of 48 people (16 female and 32 male) took part in the laboratory study. All participants satisfied the criteria of normal vision or corrected vision (visual acuity 0.8), stereopsis and colour vision. Apart from these physiological requirements, the groups were formed according to the following criteria: homogeneous age, comparable spatial perception (cube test, [LBBA07]), comparable experience with augmented or virtual reality (AR/VR) and comparable experience of assembly.

- Group 1 – HMD. The participants were between 19 and 36 years old (MV: 26.8 years; SD: 4.4 years). 95.8 % used a computer every day. 58 % stated that they had little or no experience with VR. 37.5 % had experience with 3D computer games (on average 4 hours per week playing time). The average experience in LEGO assembly had a value of 3.0 – on a scale of 0 (low) to 5 (high).
- Group 2 – TMD. The participants were between 20 and 40 years old (MV: 26.0 years; SD: 4.5). All participants used a computer every day. 64.6 % stated that they had little or no experience with virtual or augmented reality systems. 50 % had experience with 3D computer games (on average 4.7 hours per week playing time). The average experience in LEGO assembly had a value of 2.9 – on a scale of 0 (low) to 5 (high).

4.5.6 Dependent and Independent Variables

In accordance with the experiment plan, a distinction was made between four independent variables (see also overview in Table 7):

- Display type (head-mounted or table-mounted)
- Augmented vision mode (perspective or static view)
- A priori presentation of the target state of the complete assembly model (rotation or assembly)
- Decomposition/composition mode (step-by-step or exploded view)

The experiment measured the following dependent variables:

- Detection time: This was the time between the appearance of the real LEGO model and the detection of the difference by the participant (max. 15 minutes). The experiment configuration measured the start and end point of this period.
- Error detection: Different cases could occur which could be represented by separate variables: a) The participant detects the difference (error correctly detected); b) The participant picks out a brick which is no different from the virtual (target) state (error wrongly detected); c) The participant does not find the difference (error not detected).
- Visual fatigue: The study assumed that this sets in quite rapidly, particularly when using a HMD. This subjective variable was therefore also included in the study.

4.5.7 Null Hypotheses and Statistical Analysis

The following null hypotheses were formulated:

- The display type has no significant influence on detection time (H_{01}) or error detection (H_{02}).

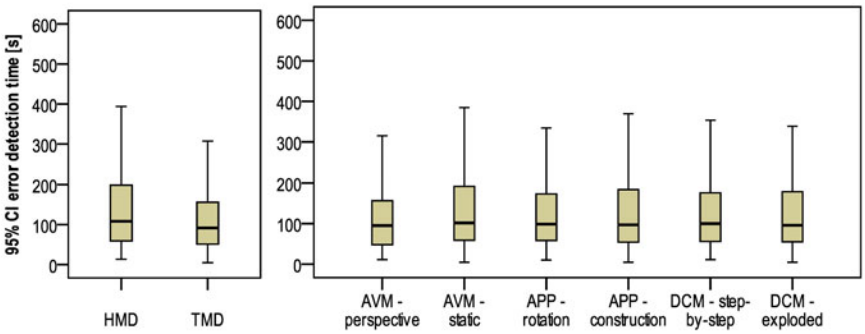


Fig. 22 *Left*: Error detection time for all participants, depending on the between-subject factor DT; *Right*: Error detection time for all participants, depending on the within-subject factors AVM, APP and DCM

- The augmented vision mode (H_{03}), the a priori presentation of the synthetic assembly information (H_{04}), and the decomposition/composition mode of the virtual model (H_{05}) have no significant influence on error detection time based on display type.
- The augmented vision mode (H_{06}), the a priori presentation of the synthetic assembly information (H_{07}), and the decomposition/composition mode of the virtual model (H_{08}) have no significant influence on the given cases of error detection based on display type.

On the basis of the data collected, inferential-statistical analyses were carried out using the program "Statistical Package for Social Science" (SPSS Version 17). First, the two data sets (Group 1 – HMD; Group 2 – TMD) were compared with respect to the dependent variables. A four-factorial repeated measures ANOVA was calculated with for the test of H01 (three within-subject factors: AVM, APP, DCM; one between-subject factor: DT). The groups were then analysed separately to identify any differences with respect to the different visualisation and interaction modes. A three-factorial repeated measures ANOVA was carried out for the test of hypotheses H_{03}, H_{04} and H_{05}. The detection time data were log-transformed before the ANOVAs were carried out (see Field 2005) to satisfy the qualitative requirements. The significance level was set at $\alpha = 0.05$. A Kolmogorov-Smirnov test was performed to examine the log-transformed data for normal distribution. Chi-square tests were carried out to verify the hypotheses H_{02}, H_{06}, H_{07} and H_{08} using the nominally scaled data from error detection. The significance level was again set at $\alpha = 0.05$.

4.5.8 Results and Interpretation

The log-transformed time data showed no significant deviation from the normal distribution. The mean values of the error detection time under the different experimental conditions are shown in Fig. 22 and Fig. 23 in the form of box plots.

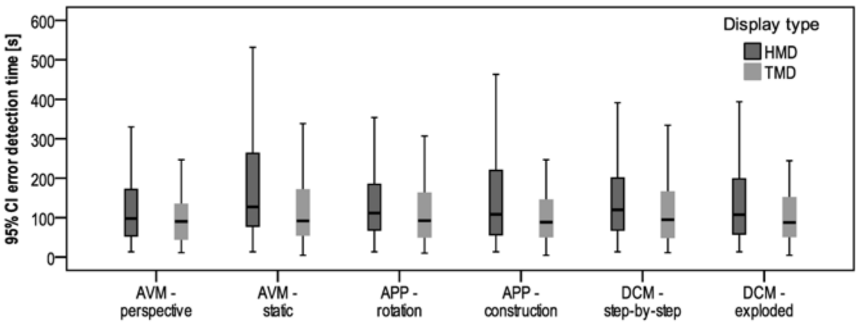


Fig. 23 Error detection time divided between the groups in the experiment (HMD, TMD) for the different conditions (AVM, APP, DCM)

4.5.9 Error-Detection-Time Results for All Participants

On average, the error detection time using the TMD was 27.64 % shorter than with the HMD. However, this difference is not statistically significant ($F_{(1,45)} = 3.001$, $p = 0.090$).

A comparison of the perspective and static views in AVM showed that error detection times in the perspective view were on average 23.45 % shorter than with the static view. This difference is statistically significant ($F_{(1,45)} = 8.854$, $p = 0.005$). In the case of the a priori presentation of the assembly information, the rotation condition led to an average error detection time that was 9.4 % shorter than under the assembly condition. However, this difference is not significant ($F_{(1,45)} = 0.043$, $p = 0.837$). When the participants worked with the exploded view, the average error detection time was only 2.2 % shorter than with step-by-step decomposition/composition. Again, this is not a significant difference ($F_{(1,45)} = 0.103$, $p = 0.749$). No statistically significant interactions were identified.

4.5.10 Error-Detection-Time Results for Group 1 (HMD)

For the perspective view in AVM, the study showed that error detection times were 29.61 % shorter than with the static view. This difference is statistically significant ($F_{(1,22)} = 8.088$, $p = 0.009$). The rotation condition of the APP mode resulted in error detection times that were on average 18.19 % shorter than the alternative assembly condition, but this difference is not significant ($F_{(1,22)} = 0.004$, $p = 0.929$). The average error detection times for both conditions in the decomposition/composition mode barely differed. With the exploded view, error detection times were an average of 2.78 % shorter than with step-by-step decomposition/composition. This is not a significant difference ($F_{(1,22)} = 0.001$, $p = 0.971$). No statistically significant interactions were identified.

4.5.11 Error-Detection-Time Results for Group 2 (TMD)

For the perspective view in AVM, error detection times were 13.07 % shorter than with the static view. This difference is not statistically significant ($F_{(1,23)} = 1.526$, $p = 0.229$). The assembly condition in APP resulted in a 2.56 % reduction in the average error detection time compared with the rotation condition. This difference is also not statistically significant ($F_{(1,23)} = 0.335$, $p = 0.568$). The average error detection times for both conditions in DCM barely differed. With the exploded view, error detection times were an average of 2.94 % lower than with step-by-step decomposition/composition. This is not a significant difference ($F_{(1,23)} = 0.148$, $p = 0.704$). No statistically significant interactions were identified.

4.5.12 Error Detection Results for All Aarticipants

The number of correctly detected errors was 36 % higher with the HMD than with the TMD. The display type significantly influences all categories of error detection (correctly detected: $p = 0.019$; wrongly detected: $p = 0.023$; not detected: $p = 0.044$). With regard to AVM, the perspective view increased the number of correctly detected errors by an average of 18.5 % compared to the static view. Compared with rotation, step-by-step assembly of the LEGO model with the APP mode enabled the user to correctly detect 14.5 % more errors. Step-by-step decomposition/composition resulted in 10.7 % more errors being correctly detected than with the exploded view. However, these differences are not significant. Error detection in the other two categories (error not detected or wrongly detected) is not significantly influenced by the levels of the independent variables.

4.5.13 Error Detection Results for Group 1 (HMD)

A comparison of the two AVMs shows that, on average, the perspective view resulted in a 19 % higher error detection probability (error correctly detected) than the static vision mode. With APP, a rotating LEGO model enabled the user to correctly detect 16 % more errors than with step-by-step assembly. With regard to DCM, the difference in correct error detection between step-by-step decomposition/composition and the exploded view was far smaller (6 %). The differences are not significant. Error detection in the other two categories (error not detected or wrongly detected) is not significantly influenced by the levels of the independent variables.

4.5.14 Error Detection Results for Group 2 (TMD)

A comparison of the two AVMs shows that, on average, the perspective view resulted in a 17.4 % higher error detection probability (error correctly detected) than the static view. With APP, step-by-step assembly of the LEGO model enabled the user to correctly detect 12.8 % more errors than with a rotating model. With regard to DCM, correct error detection in step-by-step decomposition/composition was 17.4 % higher than with the exploded view. The differences are not significant. Error detection in the other two categories (error not detected or wrongly detected) is not significantly influenced by the levels of the independent variables.

4.5.15 Visual Fatigue Questionnaire Results

As already mentioned, the participants' visual fatigue was recorded before the first and after the last cycle. A difference of 1 represented a subjectively perceived difference of 10 % in visual fatigue. The largest average increase in visual fatigue for Group 1 (HMD) was 1.1 for the item "headache", followed by 0.65 for the item "mental fatigue". The largest average increase in Group 2 (TMD) was 0.37 for the item "mental fatigue". The other differences are smaller than 5 % (0.5) and can therefore be ignored. The visual fatigue recorded was lower than expected, which indicates a good ergonomic design of the augmented vision systems. It should be pointed out, however, that the HMD was only worn for between 0.5 and 13.6 minutes at a time during the experiment. The error detection phase was always followed by a 2-to-3 minute recovery phase, during which participants filled out the questionnaires (not wearing the HMD). It is expected that a longer cycle time would significantly increase visual fatigue [PS07].

4.5.16 Discussion

4.5.16.1 Display Type

The results of the series of experiments carried out here confirm the research results of Tang et al. [TOBW04] and Meyer et al. [MSM05]. Using a HMD led to a significantly higher degree of precision in error detection, but not to a significantly shorter detection time. The lower error detection rate when using the TMD can be attributed to participants having to frequently shift their attention between the component and corresponding virtual model, and to the high mental strain this brings about. Furthermore, participants had to adapt to different light intensities between the real model and the representation on the screen. The participants consequently tended to overlook the error and thus arrived more quickly at a decision as to whether or not an error existed.

4.5.16.2 Augmented Vision Mode

Compared to the static view, AVM with perspective view resulted in a shorter average error detection time for both groups. The perspective view did, however, have less influence on the error detection time when using the TMD. The difference between the two modes was not significant here. The perspective view resulted on average in more correctly and less wrongly detected errors. Nevertheless, these differences were not significant in either group, which means the data analysis provided no statistically clear proof of a speed/accuracy trade-off.

The difference between the perspective and the static views – irrespective of the display used – is attributable to higher mental strain in the static view. In this view, the user frequently has to mentally rotate the virtual model during the error detection phase, which is a strenuous and time-consuming central process. Since Shepard & Metzler [SM71] published their classic work, we know that people's reaction times in comparing and deciding whether or not two items are identical are proportional to the rotation angle between the two representations. The study confirmed this relationship. Reaction times increase as the objects presented become more complex [FF06]. The perspective view allows users to make a direct perceptive comparison between the target and the actual assembly state, without drawing on important mental resources for rotation or translation.

As already mentioned, in the perspectively modified mode when using the HMD, the presentation of the virtual object is tracked if the turntable is rotated (vertical axis) or if the user moves his/her head (other axes). By contrast, the TMD only rotates the virtual object (vertical axis) if the turntable is rotated. These different degrees of perspective adaptation are probably the reason for the differences in performance and reliability between the perspective view and the static view in Group 2 (TMD). However, the differences are not significant.

4.5.16.3 A Priori Presentation

With APP, a shorter error detection time in rotation mode was observed for both groups. Using the HMD resulted in a shorter average error detection time, but correct error detection was lower than with step-by-step assembly. In other words, a tendency towards a speed/accuracy trade-off was observed here. The average error detection time when using the TMD was practically identical ($\sim 2\,\%$) in both rotation and step-by-step assembly. However, step-by-step assembly resulted in fewer correctly detected errors. Unlike the rotation sequence, the assembly sequence of the assembly object allowed participants to create a precise mental model of the product structure and the assembly procedure. Rotating the virtual model, which avoided the strain of mental rotation as already mentioned, resulted in faster but less reliable error detection.

4.5.16.4 Decomposition/Composition Mode

In DCM, the exploded view allowed the user to switch quickly between a fully assembled product structure and an exploded view of a product structure, and to create a precise representation in their visual-spatial memory. However, in the step-by-step mode – particularly the assembly (bottom-up) – it took a certain time before participants detected the error. Nevertheless, and contrary to the expectation, only a very small time advantage of $\sim 3\,\%$ for the exploded view was observed in both groups. This appears to be due to the effects of overlapping, which make the exact localisation of the error more difficult. Correct error detection in the exploded view was lower than with step-by-step decomposition/composition. Consequently, the rate of wrongly detected errors and errors not detected was higher, but these differences are not significant.

Based on the results of this study, the head-mounted stereoscopic vision system was further developed to support the user in remedying the assembly error once it has been identified. Interactive graphic decomposition is possible here [OMK+11]. A further study is in preparation (parts have already been conducted) that will compare different modes of visual assistance in the development of a cooperative human-robot decomposition strategy with regard to performance, reliability and mental strain.

5 Industrial Relevance

The concept of generic strategies first introduced by Porter in 1980 [Por04] provides three strategies that a company can use to achieve a competitive advantage over its rivals. The cost-leadership strategy aims to gain a competitive advantage by keeping costs down. To do so, companies can adopt a number of different approaches [MGQ95], which may have opposing characteristics – e.g. economies of scale and scope. The differentiation strategy is about developing a unique selling point using factors like image, service or design. With the focus strategy, a company focuses on a very specific customer group or market segment, although it might also focus on differentiation or cost-leadership. A company in a high-wage country produces new products domestically and pursues a strategy of differentiation. Later in the product life cycle, however, it is very likely to move production to a low-wage country to pursue the cost-leadership strategy because other providers are flooding the market to benefit from the economic success of the product. The same applies to the focus strategy, which must undergo the same change.

The concepts and technologies for cognitive automation described in this paper make it possible – by taking targeted action on the polylemma of production – to adopt a position between Porter's strategies. A Business and Technology Case provided the opportunity to put the results into practice for the first time, as a prototype application. For this purpose concepts already tested with the demonstrator cell were simulated, in collaboration with connection technology manufacturer Phoenix Contact, in a real scenario involving switch-cabinet production.

In addition to final assembly in its mass-production-style manufacturing system, Phoenix Contact operates a customer-driven switch-cabinet assembly system. This involves assembling switch-cabinet components (control units, terminals, etc.) in configurations pre-planned by the customer, mounting them onto top-hat sections

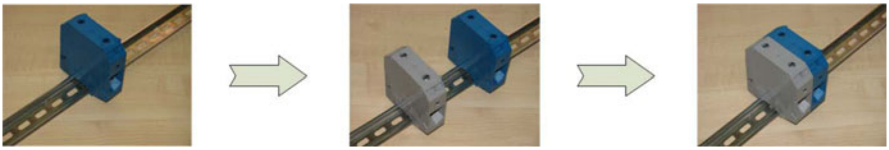


Fig. 24 Assembling switch-cabinet components on a top-hat section

and passing them on as completed modules to switch-cabinet production (module assembly). Figure 24 shows an example of this system.

Individual components must be mounted with additional plug combinations. The different mounting configurations planned are available as CAD data, as required by the CCU. The relevant mounting requirements are usually printed out, and employees then manually assemble the components on the top-hat sections. Next, even today, an image-processing-supported comparison is made between the mounting requirements and what has actually been mounted on the top-hat section.

Because the target is already available in electronic format, cognitively automating the process could bring considerable economic benefits in the future. The main challenges this involves are as follows:

- Building a continuous chain of information from the CAD system to the assembly system
- Making available robust and productive system components and joining processes for module assembly (handling devices, joining processes and aids for plugging, clamping and, if necessary, screwing)
- Applying logistical components and concepts for fitting the switch-cabinet components at the right time and in the right quantity
- Developing control concepts for establishing the ideal assembly sequence and for carrying out the assembly task itself
- Ensuring that sensors monitor the actual mounting situation and that human operators take corrective action in the case of errors.

The switch-cabinet scenario bears strong similarities to the demonstrator-cell scenario. The following correlations are relevant to the transferability of the developed concepts:

- Defined workpieces: The LEGO scenario involves fitting a large number of building bricks from the whole range. The product specification means that all characteristics relevant to assembly – such as dimensions, tolerances, and colour – are known. Unfamiliar bricks or bricks that do not fit the boundary conditions for assembly are not fed in. The modules in the switch-cabinet assembly scenario correspond to the LEGO characteristics described. The modules are also precisely specified and are only fed in after quality control. Just like any LEGO bricks fed in by accident, any modules erroneously fed in can be separated out or, if they are to be assembled later or at another stage, they can be stored or fitted.

- Flexible handling technology: The flexible gripper hand installed in the demonstrator cell was chosen for two reasons: it could grasp a LEGO brick using a variety of grips depending on the assembly situation, and if the assembly scenario changed in any way, it could grip and join other workpieces with unfamiliar shapes. The gripper hand's seven axes and its push-button sensors mean that it could also assemble the switch-cabinet modules.
- Production logistics: As in the previously described scenario, the components in switch-cabinet production must be fed in individually. The demonstrator cell uses a robot to do this, along with a group of conveyor belts with photoelectric sensors and switches. A similar logistics system would also be suitable for feeding in modules for switch-cabinet assembly.
- Individual configuration according to objective: A particular challenge for the demonstrator cell involves planning and executing assembly processes that are unknown at the time of development. The definition of the target – i.e. the description of the assembly to be assembled – is provided for each assembly in the form of CAD data, which are used to establish the necessary assembly processes. Phoenix Contact produces a description of the components to be assembled for each customer-specific switch-cabinet. In the automated switch-cabinet assembly, the assembly system is responsible for feeding in the required components and for the assembly sequence. The case under discussion also showed that the system can be controlled using a cognitive controller.

6 Future Research Topics

Future research work should aim to achieve higher degrees and levels of cognition in production systems. In doing so, it should pay particular attention to topics relating to cognitive functions and technologies for fast set-up, fast start-up, flexible scalability of throughput, and to the possibility of cooperative cellular systems. Researchers must also address the question of how to construct cognitively automated production so that it is as versatile as possible and can be operated efficiently, safely and sustainably, even in the rapidly changing environment of a high-wage country like Germany. Within this context, it is especially important to integrate humans and their superior cognitive, perceptive and sensorimotor skills.

Industrial production often uses production lines with sequentially linked stations. Each station carries out the production-process steps assigned to it and then passes the (sub)product on to the next station. The only way to compensate for failures and delays at a station is by using buffers. In extreme cases, failures and delays can bring the entire system to a standstill. Using cooperative, cognitively automated cells and control structures can make the production system more error-tolerant and flexible. A shortage of materials, a broken tool, or delays would only minimally affect overall production, because the system would be able to dynamically adapt the production flow and have other CCUs take over certain production steps. Fig-

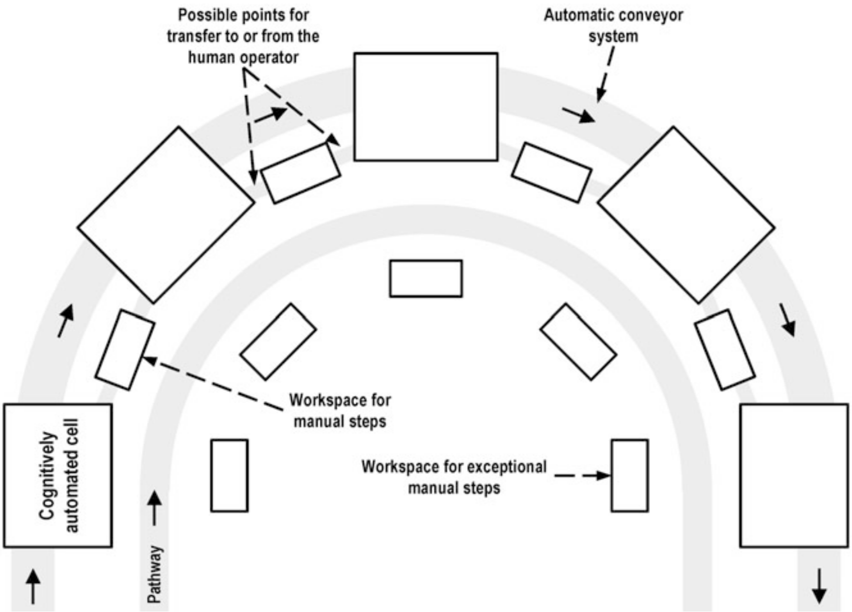


Fig. 25 Schematic construction of a cognitively automated process chain

ure 25 shows a diagram of how this kind of process chain made up of cognitively automated cells might look.

The configuration of the process chain pictured here is based on the chaku-chaku principle (literally load-load in Japanese), also known as the "one-piece-flow system". In its original form, this system involves all stations producing more or less autonomously, and a human operator simply transports the parts from station to station. The principle can achieve a high level of flexibility when it comes to handling variants and fluctuations in production, and at the same time it can reduce processing times and space requirements. A classic chaku-chaku line is generally based on a high degree of automation and a linear-cyclical linkage, in which humans simply perform "residual tasks" that offer almost no scope for making decisions or taking action. Frieling & Straeter [FS09] have investigated the productivity of such assembly systems and the health risks they pose to employees. Initial research findings from the samples they examined indicate that this kind of activity can have harmful effects on employees' mental workload (monotony and fatigue). This is presumably the result of highly repetitive assembly tasks and the lack of job rotation in the assembly concept [EDFTK10].

To counteract the disadvantages of the chaku-chaku principle, future proposals should focus on parallelising and integrating tasks within the cells and on allowing humans to interact with cognitively automated systems in an ergonomic way. Looking at a single cognitive cell within the process chain, and based on Fig. 26, we can identify the following possibilities for processing a blank, a semi-finished product or a finished product:

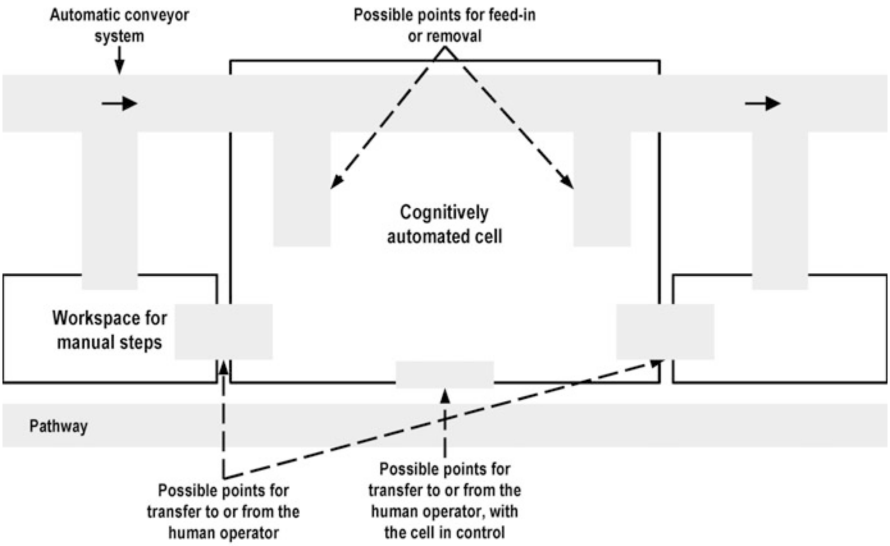


Fig. 26 Schematic construction of a cell in the cognitive process chain

- Fully-automated process: Feed-in, processing and feed-out happen automatically within the cell. Humans monitor and optimise the production process.
- Cooperative, partially automated process without removal: Feed-in and partial processing happen automatically. A human is required to manually perform some of the processing. To do so, the part in question is transported to the human operator's workspace, without leaving the secure, controlled area of the cell. While this is happening the cell can do nothing else. Once the human operator has completed the manual work, the conveyor system takes the part through the remaining automated processing steps, the measuring and checking tasks, and on to feed-out.
- Cooperative, partially automated process with removal: Feed-in and part of the processing happen automatically. A human is required to manually perform some of the processing. To do so, the part in question is transported out of the cell to a manual workspace. The part is now outside the secure, controlled area of the cell, so the cell is free to carry out other tasks while the part is being manually processed. Once the human operator has completed the manual work, he/she feeds the part back into the cell, and the conveyor system takes it through the remaining automated processing steps and on to feed-out.

If the blank, semi-finished product or finished product does not require processing in a particular cell, the integrated automated conveyor system can make it skip that cell.

This concept requires research into the following:

- New concepts and technologies that allow cooperative CCUs to coordinate and communicate material requirements, process statuses and capacities.
- Cooperative planning algorithms that can dynamically respond to changes and adapt the behaviour of individual CCUs to keep the performance, reliability and safety of the overall system at an optimal level. Several concepts can achieve this: CCUs can coordinate directly with one another, or hierarchically structured "meta CCUs" can perform higher-level planning tasks. The algorithms must be able to take into account limited availability of common resources, availability of materials, and the flow of products.
- This kind of system also makes it possible to integrate the specific skills of a human operator into the production process. Thus, using higher-level planning, work tasks that due to their complexity require a minimum level of experience can be assigned to the person best suited to the job. Furthermore, training and qualification processes can be carried out during periods when regular operations are slow (embedded training). This means that individualised production does not just apply to individualised products; it also refers to adapting production to the individual employees involved. Particularly in light of today's changing demographics, these kinds of systems could take physical impairments into account in production planning and execution and thereby offer staff support that is specifically targeted to their needs.

Given the many transfer points within the system, another field of research activities involves developing ergonomic designs for human-machine interaction. Because production is so varied and normally controlled by demand, one cannot assume that one fixed process model will emerge that humans can use for orientation. This underscores the necessity that human-machine interaction is safe and that it conforms to human expectations. Future research work should therefore investigate the following questions:

- To what extent can a cognitively ergonomic display of system status – e.g. a dynamic, multi-level flow diagram rather than the abstract, schematic displays that are common in today's control stations – increase system transparency, particularly given the fact that a human operator has to manage several cells and segments at once? Because the research focus in this case is not limited to intervening when errors arise, scientists need to develop additional concepts and methods for intuitively monitoring normal operation.
- How can targeted variations in a robot's motion sequences, in the sense of anthropomorphic kinematics and dynamics in the cell, inform the human operator – quickly, reliably and in a way that optimally responds to operational demands – that a transfer is coming up?
- Can anthropometric variables be integrated into overall system planning in such a way as to allow individual, ergonomic adaptation of things like transfer or processing points? How much flexibility do these points offer in terms of adapting to something like an unexpected staff absence?

- Can occupational safety aspects be taken into account during planning – e.g. by integrating an individual biomechanical model of the human operator – so that things like loads and torque are not set as standard, but are adapted to the specific human operator?

In conclusion, it is clear that a cognitive planning and control unit in the form of the detailed CCU concept described in this paper only provides a small example of what cognitively automated systems will be able to achieve in the field of production. Looking at the process chain as a whole, it is already possible to use cognitive mechanisms to comprehensively optimise a system beyond the boundaries of existing tolerance areas. Using a targeted combination of components – known as cognitive tolerance matching ([SIM09], see Sect. 6.1) – it is also possible to improve the quality of product. Taken together, the methods and systems developed so far offer companies in high wage countries in particular the chance to achieve considerable competitive advantages. By using cognitive mechanisms in automation, these companies can directly contribute to securing and expanding production locations in those countries.

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Erzeugung agiler Wissensprozesse in Förderschwerpunkten mittels einer interaktiven Diskussions- und Arbeitsplattform

Anja Richert, Kerstin Thöing, Sabina Jeschke

Zusammenfassung Förderschwerpunkte sind themenzentrierte Projektnetzwerke, die im Rahmen eines Forschungsprogramms eine neue Form der interdisziplinären Verbundforschung darstellen. Die spezielle Förderstruktur beinhaltet verschiedene Teil- und Fachprojekte, thematisch zugeordnet in Fokusgruppen, deren trans- und interdisziplinäre Zusammenarbeit einerseits besonders innovationsförderlich ist, andererseits aber auch eine an den neuartigen Rahmenbedingungen orientierte agile Ausrichtung der Lern- und Wissensprozesse fordert. Mit der „interaktiven Arbeits- und Diskussionsplattform" (iDA) wurde im Förderschwerpunkt „Präventiver Arbeits- und Gesundheitsschutz" ein zentrales, mediales und zielgruppenspezifisches Instrument zur Unterstützung der Lern- und Wissensprozesse eingeführt. Es ermöglicht eine intensive und gleichzeitig geographisch verteilte Interaktion der einzelnen Forschergruppen und stellt gemeinsames Wissen nach Bedarf öffentlich oder geschützt zur Verfügung.

Schlüsselwörter: Agiles Wissensmanagement, Interdisziplinäre Verbundforschung, Transferinstrument

1 Förderschwerpunkte als neue Form der interdisziplinären Verbundforschung

Seit einigen Jahren ist in der Forschung und Entwicklung der Trend zu beobachten, verstärkt in großen wissensintensiven Verbundnetzwerken zu agieren. Insbesondere die interdisziplinäre Zusammenarbeit verschiedener Forschungsdisziplinen ist zunehmend ein Charakteristikum der Verbundforschung. Beispielsweise greift sowohl die 2006 von der Deutschen Forschungsgemeinschaft (DFG) ins Leben gerufene

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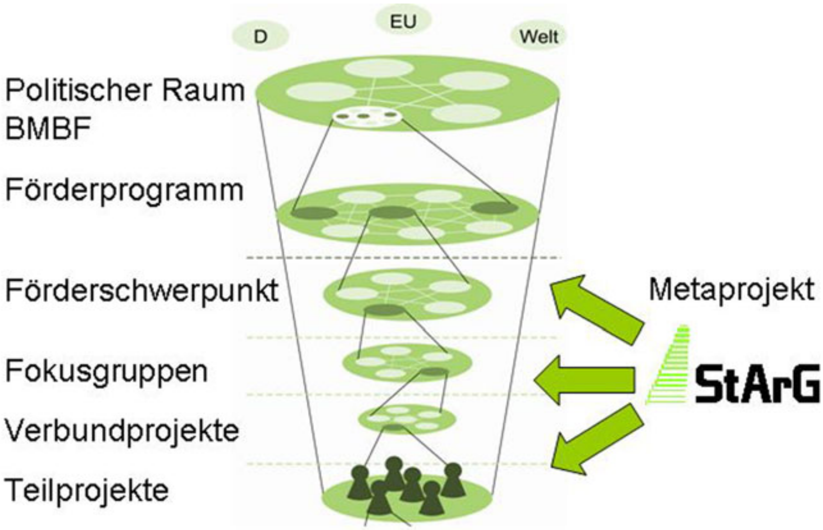

Abb. 1 Organisationsstruktur des Förderschwerpunkts

Exzellenzinitiative als auch das im gleichen Jahr in Kraft getretene Forschungsprogramm „Arbeiten, Lernen, Kompetenzen entwickeln – Innovationsfähigkeit in einer modernen Arbeitswelt" des Bundesministeriums für Bildung und Forschung (BMBF) diesen Trend auf, in dem große interdisziplinäre Projektnetzwerke wie Exzellenzcluster und Förderschwerpunkte gefördert werden. Nach Sydow [Syd01] sind die oben genannten Förderschwerpunkte dem Typ „Projektnetzwerke" zuzuordnen.

Strukturelles Charakteristikum dieser Netzwerke ist die Zusammenarbeit auf verschiedenen Forschungsebenen (Teilprojekte, Subnetzwerke etc.). So werden – wie im Beispiel des BMBF Förderschwerpunktes „Präventiver Arbeits- und Gesundheitsschutz" – meist mehrere Teilprojekte zu einem thematischen Verbund wie beispielsweise einer Fokusgruppe zusammengefasst. Mehrere dieser Verbünde (Fokusgruppen) bilden einen Förderschwerpunkt, die einem Förderprogramm zugeordnet sind und in einem bestimmten politischen Raum des jeweiligen Förderers wirken (siehe Abb. 1).

Aufgrund der stetig wachsenden Dynamik und Komplexität („Dynaxity" vgl. [TRH06]) der Lebens- und Arbeitswelten stellt die Organisation von Forschungs- und Entwicklungstätigkeiten in großen zumeist interdisziplinären wissensintensiven Projektnetzwerken ein wissenschaftlich vielversprechenden Ansatz dar. Projektnetzwerke richten ihre Innovationsziele auf spezifische Themenfelder aus. Die Initiierung von Projektnetzwerken folgt oft einem politisch, wirtschaftlich oder wissenschaftlich aktuellen Forschungs- oder Entwicklungsbedarf. Demnach –

und aufgrund der i. d. R. eher hohen Fördersumme – ist die Erwartung an die Innovationsleistung vergleichsweise hoch [Syd01]. Netzwerke dieser Art werden übereinstimmend von einer Mehrzahl an Autoren als besonders vorteilhafte Konstellation für die Produktion, den Transfer und die Nutzung von Wissen und Informationen beschrieben und entsprechend ihrer Fähigkeit, überlegenes Wissen zu entwickeln und zu vermarkten, als wissensintensive Organisationen charakterisiert [HOI03, KM03].

Durch die Zusammenführung bislang getrennter Kompetenzen und der Neukombination wissenschaftlichen und technischen Wissens auf allen Ebenen der Projektorganisation lassen sich Innovationen grundsätzlich besser als in anderen Formen der Strukturbildung (z. B. Outsourcing, Joint Ventures etc.) hervorbringen. Neben weiteren Faktoren führt insbesondere die reduzierte Hierarchie zwischen Netzwerkpartnern und -management dazu, dass klassische Verfahren (betriebliches Vorschlagswesen, kontinuierliche Verbesserungsprozesse etc.), die bei der Organisationsentwicklung eine wesentliche Triebfeder sind, in solchen Netzwerken nicht greifen [Dru93, Hee93, Hei03, Sau05, SW00]. Demnach stellt diese Form der Verbundforschung neuartige Anforderungen an Wissensprozesse, die nachfolgend am Beispiel des Förderschwerpunkts „Präventiver Arbeits- und Gesundheitsschutz" erläutert werden.

2 Wissensprozesse in Förderschwerpunkten

Das Netzwerk „Förderschwerpunkt Präventiver Arbeits- und Gesundheitsschutz" beispielsweise besteht aus fünf Subnetzwerken (Fokusgruppen), wobei die Fokusgruppen jeweils von einem Fokusgruppensprecher koordiniert werden. Ziel der Bündelung von Forschungsprojekten in Subnetzwerken ist die gezielte Erzeugung von Synergien zwischen den Projekten, die den Austausch von Forschungserkenntnissen, die Erarbeitung anwendungsorientierter Lösungen und den Forschungstransfer der Projektergebnisse befördern sollen. Zusätzlich sollen die Fokusgruppen untereinander vernetzt agieren und dadurch sowohl zu einer erhöhten Wahrnehmung des „Präventiven Arbeits- und Gesundheitsschutzes" auf politischer, wirtschaftlicher und gesellschaftlicher Ebene beitragen. Eine wesentliche Herausforderung ist darüber hinaus, das bestehende Verständnis des Begriffes „Prävention" durch zeitgemäße und innovative Forschungsergebnisse gezielt zu erweitern.

Organisationsformen des Typs „Projektnetzwerk" erfordern aufgrund ihrer flachen Hierarchiestruktur und der gleichzeitig hohen Erwartungen an Innovationsfähigkeit neue Vorgehensmodelle und Instrumente zur Gestaltung effektiver Lern- und Wissensprozesse. Diese Lern- und Wissensprozesse lassen sich aufgrund der hohen Strukturkomplexität der Verbundnetzwerke nicht „global" gestalten, sondern sollten iterativ auf verschiedenen Ebenen erzeugt werden. Daher ist es hilfreich die einzelnen „Stufen" der Erlangung von Innovationsfähigkeit zu beachten, wie beispielweise North [Nor98] sie in der „Wissenstreppe" darstellt (siehe Abb. 2).

Um die Wissensprozesse auf allen Ebenen der beschriebenen Netzwerkorganisationen zu befördern, empfiehlt sich aus wissenschaftlicher Sicht eine gegenstands-

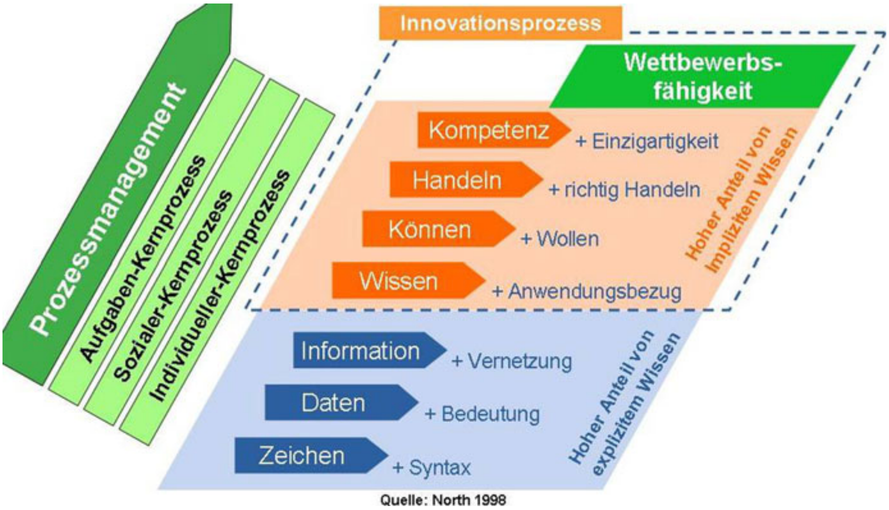

Abb. 2 Wissenstreppe nach [Nor98]

begründete, iterative Vorgehensweise. Dabei sind für diese Organisationsform taugliche Methoden, Verfahren und Instrumente sowohl auf der Aufgabenkernprozessebene als auch hinsichtlich sozialer (organisationaler) und individueller Kernprozesse zu entwickeln und einzusetzen. Um dies zu erreichen, erscheint der Rückgriff auf agile Werte, Methoden und Prinzipien ein vielversprechender Ansatz zu sein, da diese, neben einer iterierenden Vorgehensweise, Individuen und Interaktionen in den Mittelpunkt rücken.

3 Agilität als Lösungskonzept

Seit dem Beginn der 1990er Jahre entstehen – basierend auf den soziologischen Ansätzen von Talcott Parsons (AGIL-Schema) – unabhängig voneinander mehrere neue Ansätze der Softwareentwicklung, die sich als „leichtgewichtige" Prozesse bezeichneten. Der Begriff „leichtgewichtig" drückt hierbei den Gegensatz zu den Prozessen (z. B. dem V-Modell) aus, die innerhalb des Prozesses viele, aufwändige Artefakte erzeugen [Til06].

Agile Prozesse haben ein hohes Potential, flexibel auf wechselnde Kunden-Anforderungen reagieren zu können und zu jedem Zeitpunkt einen an die Bedürfnisse des Kunden angepassten Geschäftswert zu liefern. Grundlage der agilen Prozesse ist ein evolutionäres Vorgehensmodell, welches Entwicklungsphasen in kurzen Zyklen iteriert [Eck04]. Zudem rücken agile Prozesse Mitarbeiter von Softwareentwicklungsprozessen und ihre Handlungen in das Zentrum der Betrachtung. Zur Fixierung der Grundgedanken agiler Prozesse trafen sich im Februar 2001 die Vertreter 14 der bis dahin entstandenen und bereits erprobten Prozesse und einigten sich auf vier gemeinsame Werte

- Individuen und Interaktionen (gelten mehr als Prozesse und Werkzeuge),
- lauffähige Software (gilt mehr als umfangreiche Dokumentation),
- Zusammenarbeit mit den Kunden (gilt mehr als Vertragsverhandlungen),
- Änderungsfähigkeit (gilt mehr als einen Plan zu verfolgen),

auf denen zwölf Prinzipien (wie z. B. „Die Bedürfnisse des Kunden haben höchste Priorität“, „Fördere und fordere direkte Kommunikation“ etc.) basieren [man01].

Die Werte des Agilen Manifests lassen bereits erahnen, dass dieses Paradigma den oben beschriebenen Anforderungen und Ebenen der Wissensprozesse (Aufgabenkernprozess, sozialer Kernprozess und individueller Kernprozess) nahe steht. Daher wurde der im Folgenden beschriebene Auswahlprozess eines geeigneten Werkzeugs zur Förderung der Wissensprozesse im Netzwerk „Förderschwerpunkt Präventiver Arbeits- und Gesundheitsschutz“ vor dem Hintergrund der beschriebenen Anforderungen dieser Netzwerkorganisation und den agilen Werten durchgeführt.

4 Agile Wissensprozesse mit Diskussions- und Arbeitsplattformen

Um die Wissensprozesse optimal zu stützen, wurden demnach im Förderschwerpunkt zunächst Individuen und Interaktionen in den Mittelpunkt gestellt. Es wurde nach Werkzeugkonzeptionen gesucht, die auf den verschiedenen Ebenen (Teilprojekte, Verbundprojekte, Fokusgruppen, Gesamtnetzwerk) der Netzwerkorganisation eine intensive und gleichzeitig geographisch verteilte Interaktion der einzelnen Forschergruppen ermöglichen sowie bei Bedarf Informationen und Wissen öffentlich, d. h. über die Grenzen des Forschungsnetzwerks hinaus, zugänglich machen. Gleichzeitig muss der Schutz sensibler Daten und Ergebnisse auf mehreren Ebenen gewährleistet sein, um sowohl dem Förderschwerpunkt als Forschungseinheit als auch den einzelnen Projekten und Teilvorhaben einen geschützten Raum zu bieten.

Um den unterschiedlichen Bedürfnissen eines jeden Akteurs und dem prozessgebundenen Arbeiten nachzukommen, entstehen folgende Anforderungen:

- synchrone und asynchrone Kommunikationsfunktionen,
- individuell wählbare Kooperationswerkzeuge,
- intuitive Bedienbarkeit,
- Anpassbarkeit an die sich innerhalb der mehrjährigen Laufzeit eines Förderschwerpunktes verändernden Anforderungen,
- langfristige Archivierung von Forschungsergebnissen,
- einfaches Auffinden und Abrufen von Daten.

Nach einer Erprobungs- und Testphase mit mehreren Arbeitsplattformen wurde das System „metacoon“ der Entwicklerfirma metaVentis als Lösung zur Bewältigung der beschriebenen Anforderungen identifiziert und als „interaktive Arbeits- und Diskussionsplattform“ – kurz „iDA“ im Förderschwerpunkt „Präventiver Arbeits- und Gesundheitsschutz“ pilotiert. Das zur Klasse der Lernmanagement-

Abb. 3 Schematischer Aufbau von iDA

Systeme zählende metacoon-System (http://www.metacoon.net/) basiert auf dem Konzept kooperativer Wissensräume [CJLS07] und – damit verbunden – einer verallgemeinerten Raum-Metapher [GR03].

Metacoon erlaubt durch seine Funktionsvielfalt eine spezifische Anpassung an die oben genannten Bedarfe der Förderstruktur und ermöglicht durch die Fokussierung zahlreicher Interaktionsmöglichkeiten die Erzeugung agiler Wissensprozesse. Das ursprüngliche Lernmanagement-System „metacoon" mit Autorenumgebung wurde in Aufbau und Funktion umstrukturiert und spiegelt auch systemtechnisch den Aufbau und die Vernetzung des Förderprogramms wieder (siehe Abb. 3). iDA

Abb. 4 iDA-Login-Seite des Metaprojekts StArG mit Loginbox

stellt somit ein umfassendes interaktives Onlinearbeitssystem mit Breiten- und Tiefentransferwerkzeugen[1] bereit.

Die Metaprojekte eines jeden Förderschwerpunktes, der in iDA vertreten wird, bieten über ihren Internetauftritt eine Login-Seite zur Plattform an (siehe Abb. 3 und Abb. 4). Über diese kann die Plattform von registrierten Projektleitern, Projektnehmern, Fokusgruppensprechern und eingeladenen Interessierten des Förderprogramms mittels Benutzername- und Passworteingabe zeit- und ortsunabhängig betreten werden.

Der gemeinsame Eingangsraum aller Nutzer erfüllt verschiedene Funktionen: zum einen dient er als Mitteilungsportal des Projektträgers im DLR für die Förderschwerpunkte. Über eine Pinnwand und weitere Funktionen, wie beispielsweise Mailverteiler und Sofortnachrichten, lassen sich hier Neuigkeiten, die alle Mitglieder der Förderschwerpunkte betreffen, schnell verbreiten. Weiterhin bietet der Eingangsraum einen persönlichen Datenverwaltungsbereich für jeden Nutzer, in welchem dieser Daten oder Unterlagen bearbeiten und ablegen kann. Als weiterer Service steht für die iDA-Nutzer eine Autorenumgebung zur Verfügung, in der mit Online- und Offline-Autorenwerkzeugen unter anderem Webvorträge gestaltet oder

[1] Unter Breitentransferwerkzeugen werden im Kontext dieses Förderschwerpunktes Methoden zur Informationsweitergabe verstanden, mit Tiefentransferwerkzeugen hingegen sind Lernmethoden gemeint.

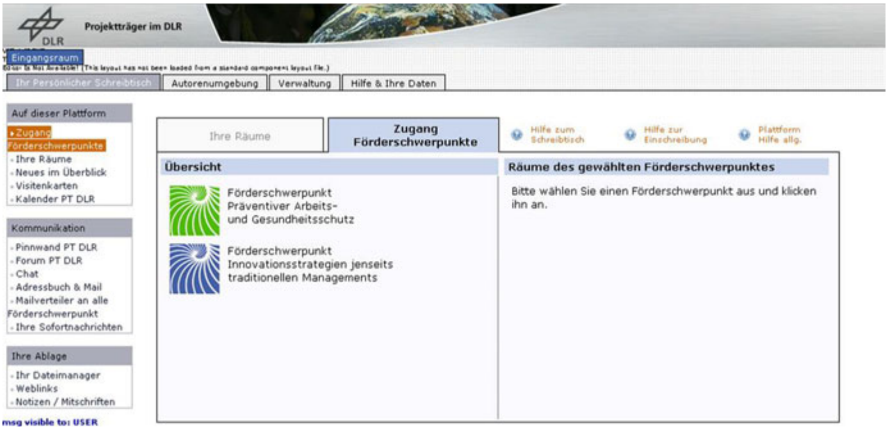

Abb. 5 Eingangsraum der iDA-Plattform

Abb. 6 Virtueller Projektarbeitsraum

Grafiken, Animationen sowie Audio- und Videodateien bearbeitet werden können. Nur für die Administratoren sicht- und damit betretbar, befindet sich im Eingangsraum ebenfalls die Plattform-Verwaltungsumgebung, unter der Benutzer, Gruppen, Räume und System administriert werden.

Über den Eingangsraum können die Förderschwerpunkte direkt angewählt und damit die dazugehörigen Räume betreten werden (siehe Abb. 3 und 5). Auf der Plattform ist die Einrichtung unterschiedlichster Raumarten je nach Bedarf möglich. Diese können nach Verwendungszweck mit unterschiedlichen Werkzeugen und Funktionen ausgestattet werden.

In den Räumen der Projekte und Fokusgruppen können sich die Mitglieder über deren Inhalte und laufende Forschungen informieren und mit den Projektleitern oder Projektnehmern über interne Sachverhalte diskutieren (siehe Abb. 6). Zahlreiche, leicht bedienbare Werkzeuge gestalten den Forschungstransfer auf der Plattform aktuell und individuell. Kurze Notizen, Neuigkeiten und Erinnerungen finden auf Pinnwänden Platz, Kalender informieren über alle wichtigen Termine. Mittels Mailverteiler sind alle Mitglieder schnell und unkompliziert erreichbar. Die Aktivierung der zahlreichen Instrumente erfolgt zielgruppenorientiert, so dass ausschließlich für den Nutzer und seine Bedürfnisse relevante Funktionen sichtbar sind (Individualisierung der Benutzeroberfläche). Während die externe Webseite des Eingangsraumes derzeit durch das Metaprojekt StArG als Login-Seite für iDA genutzt wird (siehe Abb. 4), können die Projekte, sofern sie dies wünschen, über die öffentlichen Webseiten ihrer Räume ihre Arbeit online präsentieren. Damit stellt iDA eine Unterstützung der Öffentlichkeitsarbeit der Projekte dar.

5 Role-out von iDA auf weitere Förderschwerpunkte des Projektträgers im DLR und Fazit

Die aufgeführten anwendungsspezifisch ausgeprägten Informationen haben iDA zu einem geeigneten zentralen, medialen, zielgruppenspezifischen Transferinstrument für den Wissensaustausch innerhalb der wissenschaftlichen Community gemacht. Nach den bisherigen Erfahrungswerten spielen neben den auf die Bedürfnisse des agilen Wissenstransfers von Netzwerken abgestimmten Eigenschaften des medialen Transferinstrumentes an sich jedoch noch weitere Faktoren eine wichtige Rolle für eine erfolgreiche Nutzung der Plattform. So ist die recht- und frühzeitige Einführung schon im Entwicklungsprozess einer Kommunikationsstruktur des sich organisierenden Netzwerkes wünschenswert, um die Plattform als zentrales Wissenstransfermittel zu etablieren. Da die Einführung von iDA in den Förderschwerpunkt „Präventiver Arbeits- und Gesundheitsschutz“ erst relativ spät erfolgte, war die Akzeptanz aufgrund der schon bestehenden Kommunikationswege zunächst gering. Aus diesem Grund war während der Einführungsphase ebenfalls eine weitläufige Informationsverbreitung über die Verfügbarkeit und den Nutzen der Plattform sinnvoll. Ebenso musste durch die Bereitstellung nur auf der Plattform vorhandener und zugänglicher Daten und Informationen erst eine Nutzenrelevanz für die Mitglieder des Netzwerkes geschaffen werden, um damit die Akzeptanz in der Frühphase der Einführung zu erhöhen. Gemessen an den daraufhin angestiegenen Nutzerzahlen und den sehr guten Ergebnissen qualitativer Umfragen sowie dem wachsenden Datenvolumen wird die Plattform nach diesen anfänglichen Schwierigkeiten intensiv genutzt. Innerhalb eines Jahres trugen sich 120 aktive Mitglieder ein; auf der Plattform wurden insgesamt über 2500 Zugriffe registriert. Besonders die Pinnwand im Eingangsbereich entwickelte sich zu einem beliebten Kommunikationsmittel, über das die einzelnen Projekte Informationen zu bevorstehenden Terminen und Dokumente für den gesamten Förderschwerpunkt zur Verfügung stellen. Anfragen aus anderen Förderschwerpunkten bestätigten, dass das Konzept eines solchen zentralen Transferinstruments auch dort gewünscht wird.

Im Förderschwerpunkt „Präventiver Arbeits- und Gesundheitsschutz" etablierte sich iDA somit so erfolgreich, dass zusammen mit dem Projektträger im DLR beschlossen wurde, iDA schrittweise zu einer gemeinsamen Plattform für weitere Förderschwerpunkte aus dem BMBF-Forschungs- und Entwicklungsprogramm einschließlich dem schon bestehenden Förderschwerpunktes „Innovationsstrategien jenseits traditionellen Managements" auszuweiten. Dabei soll iDA kontinuierlich weiterentwickelt und hinsichtlich der Anforderungen der Nutzer angepasst werden. Dies ist unter anderem möglich, weil die Basistechnologie der Software auf einem modularen Baukastensystem beruht, wodurch sich Weiterentwicklungen leicht einbinden lassen (open source). Anstatt mit jedem zukünftigen Metaprojekt neue Plattformen zu schaffen, die nach Beendigung des Förderzeitraumes nur noch wenig genutzt werden und damit kaum nachhaltig sind, wird die Fortführung und Weiterentwicklung von iDA in Zukunft den agilen Wissenstransfer in den Forschungsnetzwerken und die Nachhaltigkeit der erarbeiteten Forschungsergebnisse sichern.

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An Incremental Online Heuristic for Evaluating the Feasibility of the m-VRPTWAR

Christian Tummel, Christian Franzen, Eckart Hauck, Sabina Jeschke

Abstract In this paper, a heuristic approach for evaluating the feasibility of an instance of the Multi-Depot Heterogeneous Fleet Vehicle Routing Problem with Time Windows and Assignment Restrictions (m-VRPTWAR) is presented. The heuristic approach tries to find a feasible solution by solving two sub-problems of the m-VRPTWAR: a 3-Dimensional Variable-sized Bin-Packing problem (3DVSBPP) and a Traveling Salesman Problem with Time Windows (TSPTW). In order to address the first problem, an online algorithm is presented. This algorithm expects shipments to be inserted in an online fashion and assigns them to freight routes by first-fit. Repacking already assigned shipments is permitted. The TSPTW part of the problem is addressed by a 2-phase heuristic that is based on algorithms presented in Savelsbergh (1985) and Ascheuer (1996). If there is no feasible solution for a new shipment, this shipment will be rejected. The heuristic approach is evaluated by solving several large-scale scenarios and monitoring the rejection rate of the algorithm.

Key words: Vehicle Routing, Time Windows, Assignment Restriction, Heuristic, Online Algorithm

1 Introduction

In this paper a heuristic approach for evaluating the feasibility of an instance of the Multi-Depot Heterogeneous Fleet Vehicle Routing Problem with Time Windows and Assignment Restrictions (m-VRPTWAR) is presented. In this problem an assignment of a set of shipments to a set of freight routes that minimizes the unused cargo volume of the vehicles has to be determined. The assignment of each ship-

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ment is restricted to a subset of the freight routes. Furthermore, the shipment has to be delivered in a specified time window. Thus it is necessary to determine an order of the shipments of each freight route that guarantees the observance of all time windows. An introduction to this problem, including an ILP (Integer Linear Program) formulation and first calculation results for solving the problem to optimality, can be found in [TFHJ11]. In further research, it is required that for a given set of shipments and freight routes there always has to be a feasible solution. In a real-life example that assumption might be critical. It cannot be excluded that there is a shipment that will not fit in any vehicle or that the time window of a shipment conflicts with another time window. For that purpose a heuristic algorithm is developed that will be able to evaluate the feasibility of an instance of the m-VRPTWAR. The algorithm expects the shipments to be added to the problem instance in an online fashion and separately evaluates the feasibility after each addition of a shipment. If no feasible solution can be found the recently added shipment will be rejected.

Further down a heuristic algorithm is introduced that tries to find a feasible solution for an instance of the m-VRPTWAR by solving two sub-problems: a 3-Dimensional Variable-sized Bin Packing Problem (3DVSBPP) and a Traveling Salesman Problem with Time Windows (TSPTW). The connection of these problems and the overall complexity of finding a feasible solution for the m-VRPTWAR will be discussed in the next section.

2 Complexity

In the introductory work [TFHJ11] it could be shown that the m-VRPTWAR includes two known sub-problems, the Bin-Packing Problem (BPP) and the Traveling Salesman Problem with Time Windows (TSPTW). This fact has been used to prove that the optimization problem is NP-hard. First of all it shall be shown that the decision, whether a feasible solution for an instance of the m-VRPTWAR exists or not, is a NP-complete problem, in a similar way.

The problem of deciding whether an instance of the m-VRPTWAR can be solved is NP-complete. We are given a problem-instance Π with one single freight route l_1 and the shipments $S = \{s_1, \dots, s_N\}$. Suppose it is possible to assign all shipments to this freight route l_1 without exceeding its capacity or breaking the assignment restrictions. For this instance of the m-VRPTWAR it has to be verified if an order of shipments exists, for which all delivery time windows can be met. This is equal to the feasibility problem of the "Traveling Salesman Problem with Time Windows" (TSPTW) according to [CMT81], which, as shown in [Sav85], is a NP-complete problem. Since the feasibility problem of the m-VRPTWAR itself obviously belongs to the complexity class NP and furthermore includes the feasibility problem of the TSPTW as a special case, the assumption is proven.

In addition to the above remarks, the NP-completeness of the solvability problem can be derived from the proof of the optimization problem's NP-hardness in [TFHJ11]. Thus the m-VRPTWAR includes the Bin-Packing Problem as a special case, the NP-completeness of the corresponding decision problem is indicated. This makes clear, that the solvability problem itself can only be solved with high computing complexity, even if only very few shipments are assigned to the freight routes, so that the order of the shipments can be determined relatively fast. Due to the solvability problem's complexity, the chosen heuristic approach seems to be suitable for determining a m-VRPTWAR-instance's solvability.

3 Related Work

The Multi-Depot Heterogeneous Fleet Vehicle Routing Problem with Time Windows and Assignment Restrictions is a relatively new problem class. There does not exist any preliminary work in scientific literature at this point, which is relevant for this publication. Regarding an exact solution method and the formulation as ILP, we refer to [TFHJ11]. As mentioned before, it is possible to divide an instance of the m-VRPTWAR into a Bin-Packing Problem and a Traveling-Salesman Problem with Time Windows. Therefore it does certainly make sense to analyze existing literature regarding the solution of these sub-problems. The classical Bin-Packing Problem consists in distributing N objects of the defined weight w_i into M bins of equal capacity c, in such a way that as few bins as possible are needed to store all objects. "Variable-Sized Bin-Packing" (VSBPP) according to [FL86] is a version of the BPP where the capacities of the bins differ. Thus in this case not the number of bins, but the required total capacity should be minimized. Furthermore both problem-models have been extended to higher dimensional problems, where not only a weight but a weight-vector $\vec{w}_i = (w_i^1, w_i^2, \dots, w_i^d)$ of the objects is given. The bins' capacities are consequently also defined as vectors. In this case one speaks of "d-Dimensional Bin Packing" (d-DBPP) or "Vector Bin Packing" (VPP). "3-Dimensional Variable-Sized Bin-Packing" (3DVSBPP) corresponds to the problem addressed in this work, except for taking delivery time windows and assignment restrictions into account. The three dimensions are cargo volume, payload limit, and maximum number of shipments assigned to a freight route. There will be taken a closer look at this relation in the description of the heuristic. The classical BPP has been discussed extensively in scientific literature and was one of the first problems, for which the approximate solving methods have been tested for their asymptotical worst-case performance.

Definition 1 (Asymptotical worst-case performance of Bin-Packing Problems). Let L be the list of objects in a Bin-Packing Problem, and let A be an approximate algorithm for this problem. Let $A(L)$ be the number of bins required for the solution by algorithm A, and let $OPT(L)$ be the number of bins of an optimal solution. According to [Sei01], the definition of the asymptotical worst-case performance of algorithm A is represented as

$$R_A^\infty = \limsup_{k\to\infty} \sup_L \left\{ \frac{A(L)}{OPT(L)} \middle| OPT(L) = k \right\}$$

The most common solution methods for the BPP are "First-Fit" (FF) and "Best-Fit" (BF) with a worst-case performance of $\frac{17}{10}$, as well as "First-Fit Decreasing" (FFD) and "Best-Fit Decreasing" (BFD) with a performance of $\frac{11}{9}$. An elaborate overview of these and further algorithms for the classical BPP and their asymptotical behaviour is given in [CGJ97]. The work in [KP03] relies on the idea of the FFD and BDF algorithms and adapts these to the VSPBPP. The resulting algorithms "Iterative First-Fit Decreasing" (IFFD) and "Iterative Best-Fit Decreasing" (IBFD) achieve a worst-case performance of $\frac{3}{2}$. These algorithms use the FFD and BFD algorithms respectively, to find a feasible solution for the VSBPP and then go through a phase, in which further feasible solutions are generated through iteratively redistributing the objects. At the end, the best of these solutions is selected. If the objects' weights and the bins' capacities are in a defined relation, IFFD and IBFD always find the optimal solution. Further algorithms for the VSBPP have been proposed amongst others in [EL08] and [ONvV10].

In addition to the introduced algorithms there are online algorithms for both bin-packing variants, where the assumption is made that not all objects can be assigned to the bins at the same time, but have to be added to the system sequentially. For the BPP especially the "Next-Fit" Algorithm according to [Joh73], which has a performance of 2, and the HARMONIC Algorithm in [LL85] are to be mentioned (cf. [Sei01]). The latter has been adapted to the VSBPP in [Csi89] as VARIABLE HARMONIC Algorithm. The author of [Sei00] was able to show that under certain circumstances this algorithm is an optimal approximative algorithm for the VSBPP. Another solution method for the BPP, which is settled between the typical offline- and online algorithms, is described in [IL99]. This method demands, like an online algorithm, that objects are added to the system and distributed sequentially, but allows to withdraw objects from a bin and relocate them. This leads to a significantly better worst-case performance compared to online algorithms, namely $\frac{5}{4}$. For the solution of the d-dimensional problem variants, usually the previously mentioned 1-dimensional methods are carried out first. Therefore weight- and capacity vectors are transformed to scalar values. Different possibilities for such a transformation, like computing the sum or product of the vector components, are discussed in [GGJY76, KM77, MCT77], and [CFLZ90]. These adapted solution methods mostly achieve a notably worse worst-case performance compared to their classical pendants, but within the online algorithms 'd-dimensional First-Fit" (d-FF) for $d \geq 2$ is considered to be the best known approximative solution algorithm for the d-DBPP, achieving a worst-case performance of $d + \frac{7}{10}$ (cf. [GKW93]). Algorithms which have been explicitly developed for multidimensional Bin-Packing Problems, are amongst others described in [LKK99] and [Eps03].

The "Traveling Salesman Problem with Time Windows" (TSPTW) like the classical TSP consists in finding an optimal circular tour through N different nodes, but additionally the time window of each single node has to be met. In scientific literature different approaches to solving the TSPTW optimally have been proposed. The first works on this topic, which are [CMT81] and [Bak83], are based on special Branch-and-Bound algorithms and were successfully implemented for problems with up to 50 nodes, yet have efficiency issues if the time windows of a problem instance are overlapping too much. In [LDD+93] a modified formulation of the problem model is used, which is designed especially for the handling of time windows. Further exact solution methods, which rely on dynamic- or constraint-programming, were examined in [DDGS95] and [PGPR98]. In [FLM02] classical optimization techniques are combined with constraint programming methods to a hybrid algorithm. These methods could successfully solve problems with up to 200 nodes. A variant of the TSPTW, where the distance between two nodes is not symmetric – the so called asymmetric TSPTW –, is described thoroughly in [AFG00, AFG01]. Especially in newer scientific literature several heuristic approaches can be found beside these exact solution methods. These heuristic approaches are mostly based on meta-heuristics like Local Search [Sav85], Tabu Search [CB96], Simulated Annealing [OT07], Genetic Algorithms [NY92, NY93], Ant Colony Optimization Algorithms [LIB10] or Variable Neighborhood Search [FdSU10]. In [GHLS98] a so called Insertion Heuristic is described, where all nodes of the TSPTW are added to a path sequentially in such a way that this path meets all time windows. As soon as the path goes through all nodes of the TSPTW, which means that a feasible solution has been found, it is optimized by iteratively deleting and re-inserting nodes. This heuristic has proved to be very robust towards overlapping time windows and in most cases finds optimal or nearly-optimal solutions. The last heuristic algorithm, which should be mentioned here, goes back to [Cal00]. It solves a special auxiliary problem exactly and afterwards transforms its solution to a solution for the TSPTW via a heuristic method. The solutions found this way were often better than those, which have been determined using the previously mentioned heuristic according to [GHLS98].

4 Heuristic Approach

The task of the heuristic developed here is to check if for a given set S of shipments and a given set L of freight routes a feasible solution of the m-VRPTWAR exists, when a further shipment s_i is added to the system. This problem is NP-complete, which means that it probably cannot be solved efficiently (if the presumption $P \neq NP$ holds). Therefore a suitable strategy might be dividing this problem into less complex sub-problems. Like mentioned before, solving the 3DVSBPP and TSPTW as sub-problems seems to be the task. In the following, heuristics for these two sub-problems shall be presented, which can then be combined to a heuristic for the m-VRPTWAR.

4.1 Heuristic for the Bin-Packing Sub-Problem

In this chapter at first delivery time windows are not taken into account. This means the only task is to find a feasible assignment of the shipments to the freight routes.

Yet, the shipments are not known from the beginning, but step by step added to the system. Thus it is a typical application for online algorithms. Now, one could think about redistributing all previously added shipments, when a new shipment is added, to use the advantages of offline algorithms. But presumably in a realistic scenario the number of shipments is so big, that regarding the heuristic's performance, such an offline strategy would be too time-consuming. Since repacking shipments from one freight route to another is not strictly excluded in the problem, it nevertheless makes sense to adopt it in the algorithm at least to some limited extent (semi-online algorithm). As shown in [IL99], the algorithm can be considerably improved this way.

If time windows are not taken into account in the problem described above, it is the severally mentioned Bin-Packing Problem. More precisely it is the "3-Dimensional Variable-Sized Bin Packing Problem" (3DVSBPP), since for every freight route there are the three dimensions cargo volume, payload limit, and maximum number of shipments assignable to a freight route ("3-Dimensional"), and the maximum value of these three dimensions can vary for each freight route ("Variable-Sized"). The assignment restrictions are problematic since they are normally not considered in the Bin-Packing Problem. However, if a single shipment s_i is considered, which has to be assigned to one of the freight lines of set B_i, the problem can again be considered a Bin-Packing Problem. Therefore, in the problem dealt with here, for each shipment a local instance of the 3DVSBPP has to be solved. It is obvious, that through an optimal assignment in these local instances, also globally an optimal assignment is achieved. Hence, despite assignment restrictions, it makes sense to search for a heuristic for the 3DVSBPP in the following. Several methods of different authors for solving the Bin-Packing Problem have already been presented. For the 3DVSBPP, however, no heuristic solution method has been proposed, yet. Thus in the following it cannot be relied on a proven heuristic. Like it is shown in [GKW93], the First Fit Algorithm with an asymptotical worst-case performance of $d + \frac{7}{10}$ for $d \geq 2$ is the best known online approximation-algorithm for the d-DBPP, known. Therefore, this algorithm shall form the basis of the algorithm to be developed, which will be called "Repacking First Fit" (RFF) Algorithm. First the algorithm tries to find a freight route to which the shipment can be assigned, using the First Fit Algorithm. If no such freight route exists, the repacking-phase is initiated. Thereby it is tried to take back an already assigned shipment in such a way, that the freight route is preferably filled completely, after assigning the new shipment to it. This approach is supposed to make room for the new shipment on the one hand, and on the other hand to ensure that as the cargo volume of the freight routes is utilized as much as possible. The RFF Algorithm can be described as follows:

Repacking First Fit (RFF) Algorithm

1. Initialise the algorithm with set L of freight routes. At the beginning each of these freight routes is empty.
2. Wait until a new shipment s_{new} is added to the system.

3. Use the First Fit Algorithm to search for a freight route, to which the shipment s_{new} can be assigned. This assignment has to be feasible. If such a freight route is found, assign the shipment to this freight route and go back to step 2.
4. If no such freight route is found, search for the freight route which has the least remaining capacity, after a shipment which has already been assigned to this freight route is replaced by s_{new}. The replacement must not lead to an infeasible solution.
5. If no freight route is found, the shipment s_{new} has to be rejected. Go back to step 2.
6. If the maximum repacking-depth is reached, all withdrawals have to be revoked and the originally new shipment has to be rejected. Go back to step 2.
7. Otherwise, withdraw from the previously chosen freight route the shipment that leads to the lowest remaining capacity after replacing it with s_{new}, and assign s_{new} to this route. The removed shipment is now considered as a new shipment and the algorithm continues with step 3.

On the one hand this algorithm demands that shipments are added to the system sequentially, but on the other hand allows repacking of a certain number of shipments from one freight route to another, for adding a new shipment. This number is called repacking depth. In the carried out calculation results a repacking depth of 6 shipments has proven suitable. It is important to pay attention that a shipment is only allowed to be removed, if it has not already been removed and repacked in the previous step. To complete the heuristic for the m-VRPTWAR, this algorithm has to be extended in such a way, that it can steadily be guaranteed that a feasible order of a freight route's shipments exists. Therefore in the following paragraph another algorithm is presented, which has to be integrated into the RFF Algorithm. The integration has to be made at the place at which the above heuristic checks the feasibility of the current assignment, thus in step 3 and step 4. This way, at this point it is not only checked if the capacity restrictions and assignment restrictions are met, but also if an order of shipments exists, which meets the time windows of each shipment. The heuristic for the m-VRPTWAR is now complete.

4.2 Heuristic for the Traveling-Salesman Sub-Problem

If only shipments are considered, which have been assigned to one single freight route, and an order of these shipments, in which all time windows are met, is being determined, this order is a feasible solution of the "Traveling Salesman Problem with Time Windows". In technical literature different algorithms for finding an optimal order of the TSPTW were proposed. For the problem described here, however, it is sufficient if the following algorithm is able to find any feasible order. Savelsbergh introduced a heuristic for an optimal solution of the TSPTW (cf. [Sav85]), which requires knowing a feasible start-solution. Therefore in these work at the same time an algorithm was presented, which enables determining such a feasible start-solution. This algorithm seems to be suitable for determing a feasible order of the shipments, and thus is adopted in the following, with slide modifications. Since this algorithm is an offline algorithm, it computes a new order for all shipments of the freight route, every time a shipment is added, instead of adding the new shipment into the existing order. However, since the number of shipments, which can be assigned to a freight route is strongly restricted, this should not affect the heuristic's execution time too bad. Moreover, the chance of finding a feasible order is increased by using such an offline strategy. The following list is a summary of the algorithm's description according to Savelsbergh [Sav85].

Start-Solution Heuristic According to Savelsbergh

1. Divide set S of shipments s_i with time windows $T_i = \langle t_i^s, t_i^e \rangle$ in the set S^- of these shipments with narrow delivery time windows and the set S^+ of those with wide delivery time windows.
2. Initialize the algorithm with start-order (s_0, s_∞). The shipments s_0 and s_∞ are therefore created with the time windows $T_0 = \langle 0, 0 \rangle$ and $T_\infty = \langle 0, \infty \rangle$, respectively, and mark beginning and end of the order to be determined.
3. For a given order $(s_0, s_{i_1}, s_{i_2}, \ldots, s_{i_N}, s_\infty)$ determine for each shipment $s_u \in S^-$ the pair of indices i_n, i_{n+1} in between of which this shipment should be put. Therefore compute the value $C_1(i_n, u, i_{n+1})$ for each pair of shipments $s_{i_n}, s_{i_{n+1}}$ in the given order, in between of which the shipment s_u can feasibly be put, and choose those indices i_n^*, i_{n+1}^*, for which C_1 is maximal. If the shipment cannot be put into any position, no feasible order exists, and the algorithm can be terminated.
4. From the set of shipments S^- choose the shipment which should be added to the present order. Therefore, compute $C_2(i_n^*, u, i_{n+1}^*)$ for each $s_u \in S^-$, with the indices i_n^*, i_{n+1}^* for s_u computed in the previous step. Select the shipment s_{u^*} for which C_2 reaches a minimum.
5. Add the shipment s_{u^*} at the position i_n^*, i_{n+1}^* and remove s_{u^*} from set S^-.
6. If S^- is not empty, continue with step 3.
7. For a given order $(s_0, s_{i_1}, s_{i_2}, \ldots, s_{i_N}, s_\infty)$, determine for each shipment $s_u \in S^+$ the pair of indices i_n, i_{n+1} in between of which the shipment should be put. Therefore compute the value $C_2(i_n, u, i_{n+1})$ for each pair of shipments $s_{i_n}, s_{i_{n+1}}$ in the given order, in between of which the shipment s_u can feasibly be put, and select those indices i_n^*, i_{n+1}^*, for which C_2 is minimal. If the shipment cannot be put at any position, no feasible order exists and the algorithm can be terminated.
8. Select from the set of shipments S^+ the shipment which should be added to the present order. Therefore compute the value $C_1(i_n^*, u, i_{n+1}^*)$ for each $s_u \in S^+$, with the indices i_n^*, i_{n+1}^* for s_u, determined in step 7. Select the shipment s_{u^*} for which C_1 is maximal.
9. Add the shipment s_{u^*} to the order at position i_n^*, i_{n+1}^* and remove s_{u^*} from S^+.
10. If the set S^+ is not empty, continue with step 7.
11. Else all shipments have been assigned and the algorithm can be terminated successfully.

When a delivery time window is considered to be narrow or wide is not explicitly defined in the algorithm according to [Sav85], but has to be chosen specifically for each application. In the measurements presented below, an interval of two hours has proven a suitable size for the time windows. The functions C_1 and C_2, which are used as selection criteria in the above algorithm, form indicators for the flexibility of an order (C_1) as well as for the increase in the total temporal length of an order (C_2). It should be mentioned, that when processing S^- and S^+ the functions C_1 and C_2 are each used in opposite ways. For an exact definition of these functions and further details of the above algorithm cf. [Sav85]. To increase the presented heuristic's efficiency, it shall be integrated into an algorithm, which has been described in [Asc96]. This algorithm first checks if several easy computable orders are feasible, and only thereafter, uses a more complex heuristic. If combined with the previously described algorithm, the following procedure arises as a result. This algorithm can now be used, in this variant, for the m-VRPTWAR heuristic. In order to do this, only the mentioned integration into the RFF algorithm is needed.

Algorithm for Determining a Feasible Order

1. For a set S of shipments, check if the trivial order $(s_1, s_2, \ldots, s_N)$ is feasible.
2. Sort the set S by the start point of the shipments' delivery time windows in an ascending order, and check if this order is feasible.
3. Sort the set S by the end point of the shipments' delivery time windows in an ascending order, and check if this order is feasible.
4. Sort the set S by the central point of the shipments' delivery time windows in an ascending order, and check if this order is feasible. The central point of a shipment's time window $T_i = \langle t_i^s, t_i^e \rangle$ is defined as $t_i^m = t_i^s + \frac{t_i^e - t_i^s}{2}$.
5. Try to find a feasible order using the start-solution heuristic according to Savelsbergh.

5 Calculation Results

To evaluate the behaviour of the just presented RFF Algorithm, different large-scale test-scenarios have been created, using a generator-tool (cf. Table 1). In the created scenarios each relation between start- and target area is served by five different trucks. An important measurement variable, which should be recorded during the tests of the algorithm, is the number of shipments which are erroneously rejected by the test. To measure this value, during generating the test-scenarios it has to be ensured that all shipments of a test-scenario can theoretically be scheduled. Otherwise, when a shipment is rejected, it is not clear if it was rejected because it could actually not be scheduled, or because the heuristic rejected it erroneously. Moreover, it should be checked how the heuristic behaves when many shipments have already been accepted and it is becoming harder and harder to schedule another shipment.

Table 1 Detailed list of parameters of different test-scenarios for the RFF Algorithm

Scenario name	Relations	Freight routes	Shipments
RFF-1500	300	1500	6040
RFF-2000	400	2000	8085
RFF-2500	500	2500	10,315
RFF-3000	600	3000	11,955
RFF-3500	700	3500	14,495

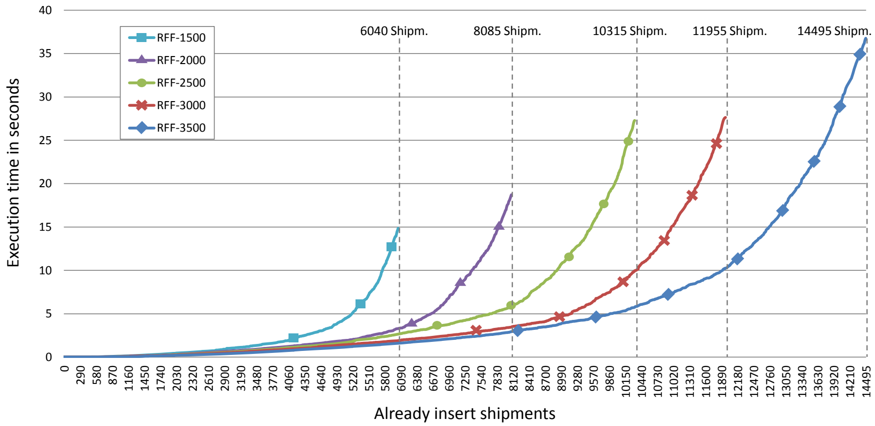

Fig. 1 Rejection rate of the RFF Algorithm for scenarios defined in Table 1

Therefore, the test-scenarios have been generated in such a fashion that an exact algorithm could calculate an assignment of the shipments to the freight routes, where no shipment is rejected and all freight routes are filled completely. The calculation results are shown in Figs. 1 and 2.

The measurements were carried out on an Intel Core 2 Quad Q9650 CPU with 4 Cores (3.0 GHz each) and 8 GB RAM. Windows 7 Professional 64-bit has been used as operating system. Furthermore the Java Virtual Machine (JVM) of SUN Java Development Kit (JDK) 1.6.0-20 has been employed, since the reference implementation of the heuristic method has been programmed in Java.

The measurements in Fig. 1 show the heuristic's behaviour for the test-scenarios, defined in Table 1. The values are plotted over the number of already added shipments. During each series of measurements the shipments were added to the scenario step by step and tested for their ability to be scheduled by the heuristic. After each test, the current rejection rate and totally required execution time was recorded and illustrated in the charts in Fig. 2. Here, execution time stands for the time which is needed for checking all shipments. It is clearly observable that the heuristic rejects very few shipments (less than 1 %), as long as only a little part of the shipments

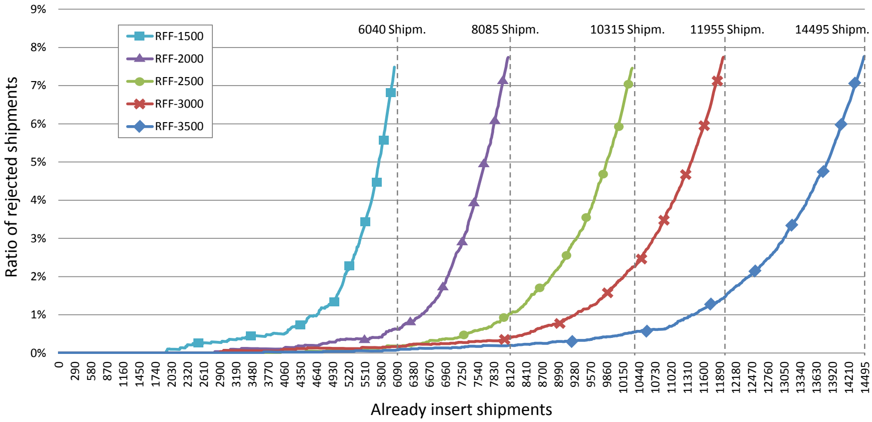

Fig. 2 Execution time of the RFF Algorithm for scenarios defined in Table 1

was added to the scenario. Only after approximately $\frac{3}{4}$ of the shipments have been added, the rejection rate increases faster and ends at approximately 7.6 % in every scenario. Regarding the heuristic's execution time a similar tendency can be observed. The greatest part of the total execution time is needed for the inspection of the last 25 % of shipments. Keeping in mind that the inspection of a shipment takes the longer the more shipments have to be repacked, this result is not surprising.

6 Conclusion & Outlook

Based on current research activities, in this work, a heuristic method for checking the feasibility of an instance of the m-VRPTWAR has been presented. The heuristic is able to carry out this test in relatively short time and thereby, in the tests of the previous chapter, only rejects 7.6 % of the shipments erroneously. Regarding the algorithm's heuristic character and the fact that we are dealing with an online process, this seems to be an acceptable result. The same is true for the algorithm's execution time, which even in the worst case is not exceeding 44ms per shipment. Using a more complex algorithm which is able to further reduce the rejection rate, but has a higher execution time, can be thought of here. An imaginable strategy for doing so would be modifying the algorithm in such a fashion that not only one, but multiple assigned shipments from a freight route, are considered in the repacking phase, to make room for a newly arriving shipment. Likewise, the algorithm could be extended in such a way, that not only one shipment, but multiple shipments at the same time, can be withdrawn from different freight routes during repacking. Both repacking strategies would lead to checking considerably more possible shipment-freight-route combinations for feasibility, and it must be assumed that this decreases the algorithms rejection rate. This has to be investigated in further research works.

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The Multi-Depot Heterogeneous Fleet Vehicle Routing Problem with Time Windows and Assignment Restrictions (m-VRPTWAR)

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Abstract In this paper, the multi-depot heterogeneous fleet vehicle routing problem with time windows and assignment restrictions (m-VRPTWAR) is introduced. The problem addresses the assignment of a set of shipments to a set of freight routes so that unused cargo volume of the vehicles is minimized. The assignment of each shipment is restricted to a subset of the freight routes. Furthermore, the shipment has to be delivered in a specific time window. Thus, it is necessary to determine an order of the shipments of each freight route that guarantees the observance of all time windows. Firstly, a formulation of an integer linear program (ILP) for solving the m-VRPTWAR is developed and the problem is proven to be NP-hard. Afterwards, the ILP is evaluated by solving several large-scale scenarios using the solvers CPLEX and Gurobi.

Key words: Vehicle Routing, Multi-Depot, Time Windows, Assignment Restriction, Integer Linear Program

1 Introduction

The subject of current research is the development of a novel logistic management system in the area of partial loads transportation. This system is based on so-called freight routes. Freight routes are fixed relations between a start and a target area that are periodically served by direct transport (see Fig. 1). Partial loads are picked-up in the start area, loaded into a single truck and transported to the target area directly without the use of handling centers. Afterwards the loads are delivered to their respective recipients. Because the areas of the freight routes can overlap, the assignment of a partial load to a freight route is ambiguous. At this point, there is

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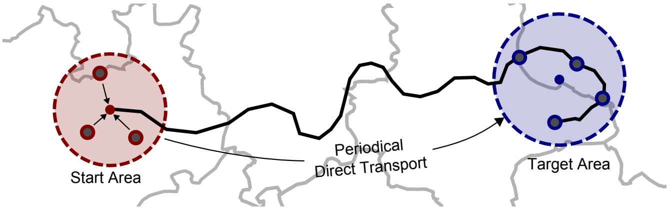

Fig. 1 Example of a freight route as a relation between a start and a target area

great potential for optimizations that can be used to reduce the unused cargo volume of the available trucks. Thus the transport network can be used more efficiently.

In the following a problem model, in form of an Integer Linear Program (ILP), is presented. This problem model determines a distribution of shipments over available freight routes, while minimizing the unused cargo volume. In this optimization process various restrictions have to be considered. The cargo volume of a freight route is always limited by its capacity. This limit refers both to spatial extent and to the total weight of cargo. In addition, it has to be possible to limit the number of shipments that will be assigned to the same freight route. Besides these restrictions there are also temporal constraints. The recipients of the shipments often specify time windows that must be considered during the delivery of the shipments. Thus, in context of the optimization process it is necessary to determine not only a distribution of the shipments over the freight routes, but also an order for the delivery of the shipments. This order must ensure that the time windows for all shipments of a freight route can be observed. Furthermore, the transport of a shipment usually is restricted to just a few days. Accordingly, the optimization technique must ensure that all shipments are delivered within the respective time windows. The last restriction to be considered here is referred to the assignment restriction in the following. As Fig. 1 shows, a shipment can only be assigned to a freight route, that covers the shipment by its start and target area. In addition, freight routes are operated only on a single day. So only freight routes are considered, that are served on a day the shipment may be transported. In general, for each shipment a set of freight routes is defined, which can be used to transport the shipment. This fact is discussed below in more detail. It is assumed that shipments and freight routes are always chosen in a way, that it is possible to determine a distribution and an order of the shipments for each freight route. Accordingly, each assignment restriction includes at least one freight route.

2 Related Work

Vehicle routing problems have always been the subject of research since the first work on this issue by [DR59]. The "Multi-Depot Heterogeneous Fleet Vehicle Routing Problem with Time Windows and Assignment Restrictions" (m-VRPTWAR), that is introduced in this paper, is a further contribution in this direction. There has been no known research done on this problem class, but there are some few related problems. In [DC07] a multilevel solution method has been shown for the "Multi-Depot Heterogeneous Fleet Vehicle Routing Problem with Time Windows". First the algorithm determines reasonable clusters of the nodes with the help of a heuristic and afterwards distributes these nodes over the trucks in a valid order by solving a Mixed Integer Linear Program (MILP). This method was able to solve problem instances with up to 100 nodes, but the deviations from the optimal solutions were at up to 30 %. Furthermore, the solution method neither takes the assignment restrictions into account nor does it aim at the minimization of the unused cargo volume. The same problem class was covered by [DMC03]. This work didn't focus on the development of a solution method, but the development of an efficient mathematical formulation of the problem model was concerned. The authors first described a compact MILP and extended it by specific rules that can reduce the size of the MILP (measured by the number of variables). It was shown, that this could significantly decrease computation time. From this work a few ideas could be adopted for the formulation of the problem described here. Considering the more general problem class of the "Vehicle Routing Problem with Time Windows", the papers of [BG05a, BG05b, BG81] and [BGAB83] may be referred.

3 Terms and Definitions

To build the following remarks on a solid mathematical framework, at first it is necessary to define some fundamental terms. Afterward these can be used to give a precise formulation of the mathematical model.

Definition 1 (Timestamp, Time Window, Time Span). A timestamp $t \in \mathbb{N}$ is a non-negative integer, that clearly references a specific point of time. All timestamps share a common basis (e. g. 01.01.1900, 0:00:00) and specify the time in seconds that has passed since this point of time. An ordered pair $T = \langle t_1, t_2 \rangle$ of timestamps with $t_1 \leq t_2$ is called time window. The difference between the timestamps $\bar{t} = t_2 - t_1 \geq 0$ is named time span.

Definition 2 (Geographic Location, Set of all Geographic Locations). An ordered pair $A = \langle \lambda, \varphi \rangle$, which components are geographic coordinates on the globe, is called geographic location. For the longitude $\lambda \in \mathbb{R}$ and the latitude $\varphi \in \mathbb{R}$ the conditions $-180° \leq \lambda \leq 180°$ and $-90° \leq \varphi \leq 90°$ hold. Let $\mathbb{W}$ denote the set of all geographic locations.

Definition 3 (Distance Function). A function $d : \mathbb{W} \times \mathbb{W} \to \mathbb{R}$ is called distance function, if for any geographic locations $A \neq B \neq C \in \mathbb{W}$ the following conditions hold:

$d(A,B) \geq 0$	(The distance always is positive.)
$d(A,B) = 0 \Leftrightarrow A = B$	(A location only has a distance of zero to itself.)
$d(A,B) \leq d(A,C) + d(C,B)$	(A detour via location C can not decrease the distance.)

(a) (b)

Fig. 2 The difference of **a** an area with distance function d_e compared to **b** an area with distance function d_t is particularly apparent on a poorly passable river

Definition 4 (Area Center, Area Dimension, Area, Set of all Areas). Let $A \in \mathbb{W}$ be a geographic location, $\bar{r} \in \mathbb{R}$ a real number and $d : \mathbb{W} \times \mathbb{W} \to \mathbb{R}$ a distance function. Then the set $G_{A,\bar{r},d} = \{X \in \mathbb{W} \mid d(A,X) \leq \bar{r}\} \subset \mathbb{W}$ is called area. In this case A is called area center and $\bar{r}$ is the area dimension. Let $\mathbb{G}$ denote the set of all areas.

The shape of an area is significantly determined by the choice of its distance function. In the following two functions are considered exemplary. The function d_e calculates the Euclidean distance between two geographic locations. By contrast, the function d_t determines the time that is needed to reach from one geographic location to another when using the road network. In areas with a well developed road network the difference between these variants is marginal, but certainly there are examples with strong differences, as shown in Fig. 2. Furthermore, the interpretation of the parameter $\bar{r}$ is only possible in the context of the associated distance function. So $\bar{r}$ can be interpreted as both: a metric or a time indication.

Definition 5 (Shipment, Set of all Shipments). Let $V \in \mathbb{W}$ be the place of dispatch, $E \in \mathbb{W}$ the place of delivery, $w \in \mathbb{R}$ the required loading metres, $m \in \mathbb{R}$ the total weight, $T = \langle t^s, t^e \rangle$ the delivery time window, $\tilde{T} = \langle \tilde{t}^s, \tilde{t}^e \rangle$ the time window of the transportation deadline and $\bar{t}$ the time span needed for unloading. The tuple $s = \langle V, E, w, m, T, \tilde{T}, \bar{t} \rangle$ is called shipment. The set of all shipments will be denoted by $\mathbb{S}$.

Definition 6 (Freight Route, Set of all Freight Routes). Let $G^s \in \mathbb{G}$ be the start area, $G^e \in \mathbb{G}$ the target area, $c \in \mathbb{R}$ the available loading metres, $n \in \mathbb{R}$ the payload limit, $a \in \mathbb{N}^+$ the total amount of shipments and $\tau = \langle \tau^s, \tau^e \rangle$ a time window, that determines a specific day. The tuple $l = \langle G^s, G^e, c, n, a, \tau \rangle$ is called freight route. The route is served on day τ by exactly one truck. If the relation between start and target area has to be served by k trucks, each of this trucks defines a new freight route $l_1, \ldots, l_k$ with its individual vehicle characteristics. Let $\mathbb{L}$ denote the set of all freight routes.

Definition 7 (Cargo Volume of a Freight Route, Cargo Volume Utilization of a Shipment). Let $s_i = \langle V_i, E_i, w_i, m_i, T_i, \tilde{T}_i, \bar{t}_i \rangle \in \mathbb{S}, i \in \mathbb{N}$ be a shipment and $l_j =$

$\langle G_j^s, G_j^e, c_j, n_j, a_j, \tau_j \rangle \in \mathbb{L}, j \in \mathbb{N}$ be a freight route. The cargo volume of a freight route is determined by the function $f : \mathbb{L} \to \mathbb{R}$. This function can have various specifications, like $f(l_j) = c_j,\ f(l_j) = n_j$ or $f(l_j) = c_j \cdot n_j$. The corresponding cargo volume utilization of a shipment is defined as the function $g : \mathbb{S} \to \mathbb{R}$ with specifications like $g(s_i) = w_i,\ g(s_i) = m_i$ or $g(s_i) = w_i \cdot m_i$. The respective specification of each function is related to the specific goal of optimization.

4 The Mathematical Model

Let $S \subseteq \mathbb{S}$ be the set of shipments $s_i = \langle V_i, E_i, w_i, m_i, T_i, \tilde{T}_i, \bar{t}_i \rangle$ with $T_i = \langle t_i^s, t_i^e \rangle, \tilde{T}_i = \langle \tilde{t}_i^s, \tilde{t}_i^e \rangle, i \in \mathbb{N}$ and $L \subseteq \mathbb{L}$ the set of freight routes $l_j = \langle G_j^s, G_j^e, c_j, n_j, a_j, \tau_j \rangle$ with $\tau_j = \langle \tau_j^s, \tau_j^e \rangle, j \in \mathbb{N}$, that are considered for the optimization. The objective of the optimization technique is to determine an feasible assignment of the shipments S to the freight routes L that minimizes the unused cargo volume of the trucks.

Definition 8 (Assignment, Feasibility of an Assignment). An assignment is a function $z : S \to L$ with

$$z(s_i) = l_j, \ \text{ if } \ s_i \in S \ \text{ is transported by freight route } \ l_j \in L. \tag{1}$$

An assignment is feasible, if it complies with all restrictions mentioned in this section.

Defining the unused cargo volume is not possible by just using the recently presented definition of an assignment. For this purpose, the functions $x : S \times L \to \{0,1\}$ and $y : L \to \{0,1\}$ with

$$x(s_i, l_j) \stackrel{\text{short}}{=} x_{ij} = \begin{cases} 1, & \text{if } \ z(s_i) = l_j, \\ 0, & \text{otherwise,} \end{cases} \tag{2}$$

$$y(l_j) \stackrel{\text{short}}{=} y_j = \begin{cases} 1, & \text{if } \ \exists s_i \in S : z(s_i) = l_j, \\ 0, & \text{otherwise,} \end{cases} \tag{3}$$

have to be derived from the assignment z. Using the definitions of the cargo volume and the cargo volume utilization, the unused cargo volume now can be determined to

$$\begin{aligned} & \sum_j \Big[f(l_j) \cdot y_j - \sum_i g(s_i) \cdot x_{ij} \Big] \\ \Leftrightarrow & \sum_j f(l_j) \cdot y_j - \sum_i g(s_i) \cdot \sum_j x_{ij} \\ \stackrel{(7)}{\Leftrightarrow} & \sum_j f(l_j) \cdot y_j - \sum_i g(s_i) \end{aligned} \tag{4}$$

Because the term $\sum_i g(s_i)$ is constant for a fixed amount of shipments $|S|$, the objective function of the ILP results in

$$\min \sum_j f(l_j) \cdot y_j. \tag{5}$$

So, minimizing the unused cargo volume can be done by minimizing the overall available cargo volume. Of course, the consistency between the functions x and y has to be ensured. For this purpose, the ILP is extended with the constraints

$$x_{ij} \leq y_j \quad \forall i, j. \tag{6}$$

If x_{ij} is 1, implying that shipment s_i is assigned to freight route l_j, the corresponding function value y_j must obtain the value 1 as well. Thus the functions will remain consistent. In addition, it must be ensured that each shipment is assigned to exactly one freight route. The necessary equation for the ILP is

$$\sum_j x_{ij} = 1 \quad \forall i. \tag{7}$$

Further constraints result from the limitation of the cargo capacity, the permissible total weight and the maximum amount of shipments of a freight route. These restrictions have to be observed for each freight route l_j. The inequalities that must be added to the ILP for that purpose are

$$\sum_i w_i \cdot x_{ij} \leq c_j \quad \forall j. \tag{8}$$

$$\sum_i m_i \cdot x_{ij} \leq n_j \quad \forall j. \tag{9}$$

$$\sum_i x_{ij} \leq a_j \quad \forall j. \tag{10}$$

Finally the assignment restrictions of the shipments have to be taken into account. Let B_i be the set of all freight routes l_j the shipments s_i may be assigned to. From now on only the assignment restrictions regarding the start and target areas of the freight routes and the transportation deadlines of the shipments will be considered. Thus the set B_i is defined as

$$B_i = \{l_j \mid V_i \in G^s_j,\ \ E_i \in G^e_j,\ \ \tilde{t}^s_i \leq \tau^s_j,\ \ \tau^e_j \leq \tilde{t}^e_i\}. \tag{11}$$

The start area G^s_j of route l_j must contain the place of dispatch V_i of shipment s_i and accordingly the target area G^e_j the place of delivery E_i. Additionally, the day $\tau_j = \langle \tau^s_j, \tau^e_j \rangle$ the freight route is served has to match the transportation deadline $\tilde{T}_i = \langle \tilde{t}^s_i, \tilde{t}^e_i \rangle$ of the shipment. Further restrictions, like special freight routes for hazardous materials, can be included by a modified definition of B_i. Restricting the assignment in the ILP can be achieved by using the constraints

$$x_{ij} = 0 \quad \forall j \notin B_i \quad \forall i. \tag{12}$$

These equations prevent the assignment of a shipment s_i to a freight route that is not part of the set B_i. Alternatively, it would be possible to remove the corresponding variables x_{ij} from the model. However, here the assignment restriction is explicitly modelled, as shown in Eq. (12).

For extending this model to consider delivery time windows, it is necessary to discuss the concept of assigning a shipment to a freight route. An assignment as defined above (Eq. (1)) does neither consider the determination of an order nor temporal restrictions between shipments. Thus, for a given assignment z and a given set of shipments S the ordering relation

$$R(z) = \{(s_i, s_k) \mid z(s_i) = z(s_k)\} \subseteq S \times S \tag{13}$$

has to be defined that determines an order for the delivery of the shipment. This order can be specified by a function $r : S \times S \to \{0,1\}$ with

$$r(s_i, s_k) \overset{\text{short}}{=} r_{ik} = \begin{cases} 1, & \text{if } s_i \text{ is delivered before } s_k, \\ 0, & \text{if } s_i \text{ is delivered after } s_k, \end{cases} \tag{14}$$
$$r(s_i, s_k) = 1 - r(s_k, s_i).$$

The function r is called ordering function. This function defines a total order of the shipments in S. Of course, in context of the problem described above it is not necessary to determine an order for all shipments but only for these shipments s_i and s_k that are assigned to the same freight route. Thus, the function values r_{ik} are only defined for shipments s_i, s_k with $z(s_i) = z(s_k)$ and $i \neq k$.

Definition 9 (Ordered Assignment, Feasibility of an Ordered Assignment). Let $z : S \to L$ be an assignment and $r : S \times S \to \{0,1\}$ an ordering function. The pair of functions $\langle z, r\rangle$ is called ordered assignment. If z is feasible and the ordering relation fulfilles all delivery time windows, the ordered assignment $\langle z, r\rangle$ is feasible as well.

Hence, the aim of the optimization technique is not determining a feasible assignment anymore, but determining a feasible ordered assignment while minimizing the unused cargo volume. For ensuring the observance of the delivery time windows by constraints in the ILP, a further auxiliary function $t : S \to \mathbb{N}$ is needed. The function value $t(s_i) \overset{\text{short}}{=} t_i$ specifies the point in time when the delivery of the shipment s_i will take place. So for two shipments s_i and s_k with $r_{ik} = 1$ and $z(s_i) = z(s_k)$ the conditions

$$t_k \geq t_i + \bar{t}_i + d_t(E_i, E_k) + \varepsilon \tag{15}$$

always hold. The function d_t is equal to the distance function described above and determines the travel time of a truck between the place of delivery of shipment s_i to the place of delivery of shipment s_k. Because the function values $d_t(E_i, E_k)$ are constant in each of these constraints, they can be evaluated in a preprocessing stage. The constant ε functions as a temporal buffer.

The function values t_i are bounded by the delivery time windows of the shipments. This restriction is considered by adding the constraints

$$t_i^s \leq t_i \leq t_i^e \quad \forall i \tag{16}$$

to the ILP. Finally, it is necessary to take the temporal mutual dependencies from Ineq. (15) into account when determining an order of the shipments. This can be achieved by the constraints (cf. [DMC03] or [DC07])

$$t_k \geq t_i + \bar{t}_i + d_t(E_i, E_k) + \varepsilon - M(1 - r_{ik}) - M(2 - x_{ij} - x_{kj}) \quad \forall i < k \ \forall k, j, \tag{17}$$
$$t_i \geq t_k + \bar{t}_k + d_t(E_k, E_i) + \varepsilon - M \cdot r_{ik} - M(2 - x_{ij} - x_{kj}) \quad \forall i < k \ \forall k, j. \tag{18}$$

Herein $M \in \mathbb{N}$ is a sufficiently large integer. The terms $M(1 - r_{ik})$ and $M \cdot r_{ik}$ ensure that for given i, k, j with $i \neq k$ only one of Ineq. (17) or Ineq. (18) has to be satisfied. Similarly, the term $M(2 - x_{ij} - x_{kj})$ achieves that the inequations are only mandatory for shipments s_i and s_k that have been assigned to the same freight route l_j. Extending the problem model with Ineq. (16) to (18) is sufficient to determine a feasible ordered assignment of shipments to freight routes.

5 Complexity

After the problem of this work has been described in detail its complexity will be studied below. For that purpose the tools of the complexity theory can be utilized (see [GJ79]).

Theorem 1 (Optimization Problem is NP-hard). *The "Multi-Depot Heterogeneous Fleet Vehicle Routing Problem with Time Windows and Assignment Restrictions" described above is NP-hard.*

Proof. Given a problem instance Π of the ILP. For Π there are no assignment restrictions $B_i = L \ \forall i$, the amount of shipments assigned to a freight route is unlimited $a_j \to \infty \ \forall j$, there are no restrictions regarding the total weight $m_i = 0, \ n_j > 0 \ \forall i, j$ and the delivery time windows are arbitrarily wide $t_i^s = 0, \ t_i^e \to \infty \ \forall i$. The cargo volume $f : \mathbb{L} \to \mathbb{R}$ is specified as $f(l_j) = 1 \ \forall l_j \in L$. For this problem instance it is not necessary to explicitly determine an order of the shipments. Because of the given delivery time windows the shipments can be arranged in any order. Instead it is possible to implicitly define an order of the shipments by the natural order of index i. According to that, the problem instance Π is equal to the "Bin-Packing Problem" (BPP) as it is described, inter alia, by [MT90]. Thus, the m-VRPTWAR contains the BPP as a special case. As a consequence, the NP-hardness of the BPP as proven by [GJ79] implies the NP-hardness of the m-VRPTWAR. □

Considering the given problem complexity it is impossible to solve large worst-case scenarios of the m-VRPTWAR to optimality within a reasonable period of time (if the presumption $P \neq NP$ holds). Hence, it is questionable, whether searching for an optimal solution is reasonable or if it is better to focus on approximation algorithms and heuristics. However, the assignment restrictions conspicuously reduce the amount of feasible assignments of shipments to freight routes so that considerably larger problem instances can be solved in the same time compared to an instance without assignment restrictions. In the latter case a naive solution algorithm would have to determine $2^{|S|\cdot|L|}$ different combinations of the function values x_{ij} and verify their feasibility. Using assignment restrictions with an average cardinality of $|B_i| = b$ there are only $2^{|S|\cdot b}$ possible combinations. Based on the description of the problem for the average case the assumption $b \ll |L|$ can be justified which implies $2^{|S|\cdot b} \ll 2^{|S|\cdot|L|}$. As a result, it might be possible to solve even large realistic problem instances within a reasonable period of time. In the best-case, finding an optimal assignment is even trivial. For $|B_i| = 1 \;\; \forall i$ the assignment of each shipment is clearly set to a single freight route. So the optimal assignment easily can be determined to

$$z(s_i) = l_j \;\text{ if }\; l_j \in B_i \;\; \forall i.$$

Afterwards an order of the shipments for each freight route has to be identified. This problem is equal to the "Traveling Salesman Problem with Time Windows". Even though this problem belongs to the NP-hard problems [FLM02] finding a feasible order should require relatively little time due to the fact that the amount of shipments assigned to a freight route is very limited (approximately $\sum_i x_{ij} < 10 \;\; \forall j$). This limitation can be deduced from the size of the shipments which are all partial loads as described above.

6 Calculation Results

To evaluate the applicability of the presented ILP for solving the described problem, several realistic test scenarios have been created by using a generator tool (see Table 1). The columns "Variables" and "Constraints" show the amount of variables and constraints of the corresponding ILP. Each relation between a start and a target area is served by five different trucks. Afterwards an optimal ordered assignment has been determined for this scenarios. For the calculation of these assignments each of the solvers CPLEX and Gurobi were used. The measurements presented in the following have been performed on an Intel Core 2 Quad Q9650 processor with 4 cores (each 3.0 GHz) and 8 GB main memory. The operating system was Windows 7 Professional 64-bit. Due to the optimization technique was implemented in the programming language Java it was necessary to run the measurements with a Java Virtual Machine (JVM). For that purpose the JVM contained in the SUN Java Development Kit (JDK) 1.6.0-20 was used. The solvers CPLEX and Gurobi were present during the tests in versions 12.2 and 4.0.2. To enable the solution of even large scenarios, both solvers were configured to swap the used main memory to a hard drive if they have exhausted the available memory of 8 GB. In addition, all calculations were limited to a duration of 1.5 hours. If a calculation took more time,

Table 1 Detailed listing of the parameters of the different test scenarios

Name of Scenario	Relations	Freight Routes	Shipments	Variables	Constraints
S1500-S(mall)			739	6645	17,461
S1500-M(edium)	300	1500	1546	14,749	44,212
S1500-L(large)			2094	20,376	63,087
S2500-S			1805	16,528	44,515
S2500-M	500	2500	2546	23,778	67,924
S2500-L			3644	35,519	109,607
S3500-S			1984	19,369	59,565
S3500-M	700	3500	3537	34,996	111,423
S3500-L			5332	54,823	183,891
S4500-S			2217	20,575	55,007
S4500-M	900	4500	4519	44,484	135,369
S4500-L			7074	72,313	234,711
S10000-S			5050	64,893	298,978
S10000-M	2000	10,000	10,122	126,974	549,774
S10000-L			15,053	186,857	787,079

it has been aborted and the relative difference of the currently available solution to the optimal solution has been indicated.

So far, the objective function of the ILP has been considered only parametrized. The cargo volume $f : \mathbb{L} \to \mathbb{R}$ has not been defined clearly. Thus, to perform the test measurements the cargo volume f of a freight route $l_j = \langle G_j^s, G_j^e, c_j, n_j, a_j, \tau_j \rangle$ with area centers A_j^s and A_j^e has been specified to

$$f(l_j) = \frac{1}{2} \cdot \left(\frac{c_j}{c_{\max}} + \frac{n_j}{n_{\max}} \right) \cdot d_e(A_j^s, A_j^e) \quad \text{with} \quad c_{\max} = \max_j \{c_j\}, \;\; n_{\max} = \max_j \{n_j\}.$$

The first part of this equation determines the capacity of the truck serving the freight route in relation to a fictitious largest possible truck with available loading metres $c_{\max}$ and a payload limit of $n_{\max}$. This ratio is weighted with the length of the freight route that is given by the Euclidean distances d_e between the area centers. As a result, small trucks driving on short freight routes are preferred for delivering the shipments. It is assumed that this leads to an economically optimized total traffic. Table 2 shows the measurements for the different test scenarios. Presented is the execution time for finding an optimal solution as well as solutions with 1 % and 5 % deviation to the optimal solution. If a timeout occured (after 1.5 hours), the deviation between the best known solution and the optimal solution has been determined. The deviation is calculated from the best lower bound of the Branch&Bound algorithm used by CPLEX and Gurobi. Thus, the deviation indicates the maximum possible gap between the optimal and the best known solution.

The results in Table 2 show that both solvers regularly fail in determining an optimal assignment in the specified time. As expected, this is associated with the

Table 2 Comparison of the solvers CPLEX and Gurobi for different scenarios in regard to execution time and memory usage

Scenario	*Gurobi 4.0.2* Opt. [s]	1 % Dev. [s]	5 % Dev. [s]	Dev. on Timeout [%]	peak Mem. [GB]	*CPLEX 12.2* Opt. Opt. [s]	1 % Dev. [s]	5 % Dev. [s]	Dev. on Timeout [%]	peak Mem. [GB]
S1500-S	15	15	3	–	0.35	3	3	1	–	0.76
S1500-M	57	57	29	–	0.89	14	12	1	–	1.05
S1500-L	–	350	25	0.0724	3.08	24	23	3	–	1.18
S2500-S	–	142	62	0.0218	1.55	24	14	13	–	1.12
S2500-M	–	483	116	0.1037	2.98	37	36	34	–	1.52
S2500-L	235	234	49	–	1.40	82	76	5	–	2.24
S3500-S	851	377	377	–	1.63	1080	31	31	–	6.71
S3500-M	–	922	787	0.0654	3.12	482	145	68	–	2.92
S3500-L	–	5365	103	0.1913	4.48	–	179	70	0.0817	63.08
S4500-S	1271	448	91	–	1.54	45	24	24	–	1.34
S4500-M	–	3153	90	0.4910	3.29	778	122	67	–	3.46
S4500-L	–	–	119	3.1608	5.46	1231	303	104	–	4.99
S10000-S	–	–	–	7.2970	5.92	–	466	466	0.1882	16.57
S10000-M	–	–	–	6.0746	11.22	–	–	1503	1.2572	20.02
S10000-L	–	–	602	3.9919	14.32	–	–	1745	2.4098	22.14

increasing size of the scenarios. Here a high number of shipments seems to be more problematic for the solvers than a high number of freight routes. This result is not surprising, since an increasing number of freight routes leads to an increasing number of possible optimal assignments, whereas an increase of the shipments reduces this number. In addition, there are also other factors that determine the complexity of a scenario. So none of the solvers was able to solve the S3500-L scenario to optimality, but for several larger scenarios an optimal solution has been found.

In a direct comparison Gurobi turns out to be clearly inferior compared to CPLEX in determining an optimal solution, since the former may not even solve half as many scenarios as CPLEX to optimality. Moreover, CPLEX is generally preferable in regard to the computation times. Furthermore, the assignments found by CPLEX in the event of a timeout are almost always closer to the optimal solution. Only in terms of memory usage Gurobi has advantages over CPLEX. However, it is assumed that the beneficial computing times of CPLEX are also due to the high memory usage. Since the main memory is not a scarce resource in the problem discussed here, the high memory usage has to be considered rather as a further advantage of CPLEX.

7 Conclusion & Outlook

In this work, an optimization technique for the disposition of shipments via freight routes has been presented. Based on a detailed description and analysis of the problem, at first a mathematical model in the form of an Integer Linear Program (ILP) has been developed. The tests in the previous section have shown that this model of the "Multi-Depot Heterogeneous Fleet Vehicle Routing Problem with Time Windows and Assignment Restrictions" abstracts the problem discussed here in an appropriate manner. This allows to include that problem class, which has not covered by the scientific literature so far, in the list of Vehicle Routing Problems. Moreover, it is possible to refine or extend the problem model in various places in future work. Thus, the cargo volume of a freight route has been defined to perform the tests, but it could not be shown that this definition also leads to the desired economic optimum. In this context, generally an extensive discussion of the objective function of the ILP is necessary. Since the distance traveled in the start and target areas is not considered yet, an extension of the objective function might be profitable. Solving the ILP using a standard solver has shown, that the solvers rapidly found good solutions for the given problem instances. In some test cases the selected solvers CPLEX and Gurobi reaching its limits and were unable to determine an optimal assignment in the available time period of 1.5 hours. However, an assignment that comes very close to the optimal solution can usually be found within a few minutes. At this point, a problem-specific solution algorithm that would certainly be able to solve larger problem instances to optimality can be developed in future work. In addition, it would be possible to preprocess a problem instance by a so-called clustering algorithm. This algorithm could try to split the set of freight routes into different clusters in a way that an assignment can be calculated separately for each of these clusters. As a result, large problem instances would be divided into smaller and thus easier solvable instances. Such a reduction of problem size, might cause a significant reduction in execution time. However, it must be examined, whether such clustering is applicable at all.

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Part IV
Target Group-Adapted User Models for Innovation and Technology Development Processes

User Adaptive Design of Active Vehicle Safety Systems with Regard to the Driver Behavior of Elderly Drivers

Max Haberstroh, Max Klingender, Qihui Huang, Eckart Hauck, Klaus Henning, Sabina Jeschke

Abstract In the paper User adaptive design of active vehicle safety systems with regard to the driver behavior of elderly drivers the research project Evaluation of active vehicle safety systems and components in regard to their safety impact on elderly drivers is presented, including its most striking results. The project is funded by the Federal Ministry of Transport, Building and Urban Development (BMVBS) and aims to answer the question if active vehicle safety systems are able to support elderly people in staying mobile. Additionally, a list of criteria for designing active vehicle safety systems in the future and recommended procedures for political decisions was developed retrospectively. Therefore an extensive market research was carried out in the beginning of the project, containing a literature research, a survey with 70 elderly people and expert interviews. During the second phase test drives combined with the answering of standardized questionnaires and special workload assessments were carried out.

Key words: Active Vehicle Safety Systems, Elderly Drivers

1 Purpose of the Study

Today, the car is the most important vehicle for the maintenance of mobility for elderly people. Most elder drivers suffer age based constraints, like worsening sight and/or hearing or decreasing flexibility and muscular strength. To compensate these age based constraints, elderly drivers develop strategies like reducing their driving speed or choosing other traffic routes [RS02]. However, not every constraint can

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be compensated this way and with a growing population of elderly drivers in most industrial societies, new solutions are needed to keep elderly people mobile and safe in their everyday life. The efficiency of drive support can be raised if criteria for age based design are considered in the development process of active vehicle safety systems.

The research project Evaluation of active vehicle safety systems and components in regard to their safety impact on elderly car drivers analyzes, whether active vehicle safety systems can support elderly drivers to stay mobile and therefore participate in everyday traffic safely. In this project several active vehicle safety systems were tested, which shall help to compensate physical, sensorial and cognitive constraints of elderly drivers. The aim of the project is to retrospectively develop a list of criteria which should help developing future age-based designs of active vehicle safety systems. Therefore the project focuses on off-the-shelf systems and their impact on the road safety of elderly drivers. There are other European projects that investigate connections between elderly drivers and traffic (e.g. AGILE – Aged people integration, mobility, safety and quality of life enhancement through driving) or mobility impaired users and ambient intelligence systems (e.g. ASK-IT – Ambient Intelligence System of Agents for Knowledge-based and Integrated Services for Mobility Impaired users). In contrast to AGILE, which concentrates on humans and how to classify illnesses of elderly associated with driving and how to help them to continue driving safely, the presented project focuses on a specific driver assistant oriented approach. ASK-IT is more technically oriented than AGILE but focuses on mobile technical devices and not on active vehicle safety systems like the described project does. The project Evaluation of active vehicle safety systems and components in regard to their safety impact on elderly car drivers is funded by the Federal Ministry of Transport, Building and Urban Development (BMVBS) and coordinated by the Federal Highway Research Institute (BASt). It follows an interdisciplinary approach in cooperation of automotive engineers and social scientists of the RWTH Aachen University.

2 Conducted Work

2.1 Market Analysis

In the beginning of the project a comprehensive market analysis of already existing active vehicle systems like anti-lock braking systems, anti-slip regulation, brake assistant and active steering was performed. This analysis clarified the potential of existing and newly developed driver assistance systems in consideration of their effects on road safety for elderly drivers.

2.2 Requirement Analysis

As a next step a requirement analysis of elderly people regarding driver assistance systems was carried out. In most industrial societies life expectancy increases while the fertility rates decrease. In the long term, this will consequently lead to two major changes in the social structure: to the first will be a shrinking population and the second will be a growing proportion of elderly in the population, One third of the population will be older than 60 years in Germany, as in most OECD countries in 2030 and the percentage of the population aged 80 and older will triple until the year 2050 [SE08]. Investigations revealed that increasing participation in the traffic and the growth of the population of the elderly people since 1998 led to a growing total number of elderly casualties per year [unf06]. In comparison with other age groups, elderly people have a lower accident rate [unf07]. The consideration of the risks of accidents in relation to the driving performance shows a clearly different result. It turns out that those elderly who still drive cars, have a higher accident risk than middle-aged groups [unf07].

Today the car's importance for elderly people is increasing, because the present group of elderly people is the first group to possess a driving license for almost their whole life. According to that, it can be assumed, that with increased mileage, the number of accidents will rise. Regarding the severity of the accident, it can be noted that accidents of elderly people are significantly more likely to have fatal consequences than those of younger people [Vor07].

The results of the requirements analysis demonstrate that elderly drivers account the car as the most desirable mean of transport [Cha94]. They also revealed that the risk to cause accidents in road traffic is higher for elderly people, the fewer kilometers they drive [KK02].

The survey carried out within the requirement analysis showed that many of the elderly drivers are aware of this risk and their constraints and are willing to use driver assistance systems to increase road safety. Especially informational and warning systems were perceived as helpful and got little rejection by the interviewed persons.

2.3 Test Runs

In the second phase of the research process test runs were carried out on a test track to evaluate the effects of active vehicle safety systems. Therefore a special research design was developed which will be presented in this chapter.

2.3.1 Driver Assistance Systems

The market analysis showed that there is a variety of driver assistance systems, that is different in its functioning, its interaction with the driver and in its objective (e.g., increase safety, comfort, etc.).

The age-related changes suggest the conclusion that especially those systems are suitable for elderly people who support the drivers independently, without requiring the driver's attention, and contribute to the reduction of the complexity of the driving task.

For the further course of the project, in consultation with the Federal Highway Research Institute (BASt), Brake Assistant, advanced Brake Assistant and Active Steering were chosen for closer examination with elder probands on the test track. Brake Assistant supports the driver during an emergency braking by maximizing the braking pressure. Advanced Brake Assistant additionally detects the distance to the front vehicle and the relative velocity by radar and optimizes the braking pressure when the driver brakes. Active Steering influences the ratio between steering wheel and the wheels depending on the driving speed.

After the evaluation of the driving tests, it will be possible to set up a category system for the assessment of active vehicle safety systems in terms of their added value for elderly drivers.

2.3.2 Experimental Vehicle

Two Audi A5 were chosen as the experimental vehicles for the tests on active steering and a Volkswagen Passat CC for the tests on Brake Assistant and advanced Brake Assistant. For the testruns with the active steering, one car was equipped with an active steering system, so that it was possible to compare one car with active steering with another car without active steering. For the recording of data from vehicles Controller-Area-Network (CAN) the CANalyzer software package was used, which was run by a laptop within the car. All necessary data were available on monitoring-network-CAN and could be read and saved from there.

2.3.3 Experimental Arrangement

All tests took place at the test track of the ika (Institute of Automotive Engineering) of the RWTH Aachen University. The test track consists of an absolutely flat circuit with a diameter of 100 m, which is tangential connected to a 600 m long and 22.5 m wide straight line. The end forms a small turning circle with a diameter of 40 m.

2.3.4 Acceptance and Workload Investigation

The acceptance and workload investigation included a survey of the attitudes of the probands towards the systems/elements of driver assistance systems before the test drive, an observation during the test drive as well as a workload assessment immediately after the individual maneuver that were driven.

To collect data about the attitude of the proband before the test drives, a standardized questionnaire was developed. In addition to demographic data, information on the driving experience and driving habits of the probands and their knowledge of the driver assistance systems to be tested were queried. The questionnaire is intended to create a comprehensive profile of attitudes of the probands, which can be used as an explanatory background for the findings of the final workload assessment.

After each driven maneuver the probands had to fill a workload questionnaire in which they evaluated the following categories. For this purpose the standardized NASA Task Load Index (NASA-TLX) was selected. The NASA-TLX quantifies subjective workload using a multidimensional scale. The six defined categories are:

Mental demand (e.g. thinking, deciding, calculation, remembering, looking, searching, etc.), Physical demands (e.g. pushing, pulling, turning, controlling, activating, etc.), Temporal demands (How much time pressure did you feel due to the rate or pace at which the task or task elements occurred?), Own performance (How successful do you think you were in accomplishing the goals of the task?), Effort (How hard did you have to work (mentally and physically) to accomplish your level of performance?), Frustration (How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complaced did you feel during the task?)

These dimensions are weighted based on a paired comparison. At first 15 pairs are formed from the six dimensions. The probands then decided which of the dimension was perceived as the more strenuous category. This comparison was done after all test drives were completed [HS88].

2.3.5 Sequence of the Test Runs

During the tests drives for the investigation of active steering the probands drove a series of three maneuvers on the test track. Different data were recorded, by which the impact of the investigated system were reviewed. All probands were asked before the driving tests about their knowledge about the function of and their attitudes towards different driver assistant system. After each maneuver, the probands were asked to fill out the NASA-TLX workload assessment for the particular maneuver. To be able to make a statement about the effect of active vehicle safety systems on elderly drivers, all driving tests were additionally done with a group of younger drivers consisting of experienced drivers aged 30 to 55 years.

To investigate the active steering three maneuvers were performed. First, the probands had to turn over the vehicle in several moves in a narrow track. Second, they had to drive through a marked out slalom course. The construction of the course forced the drivers to perform different steering movements. And third, the probands had to carry out a μ-split-full-brake-application with the left wheels on a wet rubber mat and the right wheels on asphalt. All maneuvers had to be completed with the car that was equipped with an active steering system and the one that was not. The order in which the cars and the maneuvers where selected was randomized. Only the μ-split-full-brake-maneuver was always driven last. During the test drives the steering angle, speed, acceleration and the angle of yaw were recorded.

Fig. 1 Target vehicle for braking maneuvers (ika)

To investigate Brake Assistant and advanced Brake Assistant the probands had to follow a truck with a mattress that was attached to a pole, which was used as target vehicle for the braking maneuvers (Fig. 1).

The driver of the truck was instructed to brake suddenly at different unpredictable times and places of the test track so that the probands had to perform a full-brake-application behind the mattress. The probands conducted between two and four full-brake-applications with each system – Antilock Braking System (ABS), Brake Assistant (BAS) and advanced Brake Assistant.

3 Results

3.1 General Data of Probands of the Acceptance Investigation

The group of elderly drivers consisted of 32 people. Eight female probands and 24 men constituted this group. The group of younger drivers consisted of 33 persons, five of them being female and 28 being male. The probands in the group of elderly drivers were between 64 and 74 years old, while the people in the group of younger drivers were between 35 and 50 years old. The driven kilometers per year are almost counterbalanced between the two groups. There is just a small difference between both groups. 19 % of the asked persons in the group of elderly drivers drive less than 5000 kilometers per year while only 15 % of the persons in the group of younger drivers do. In both groups there are almost the same number of people who drive more than 15 000 kilometers per year (group of elderly drivers: 34 %, group of younger drivers: 36 %) (Fig. 2).

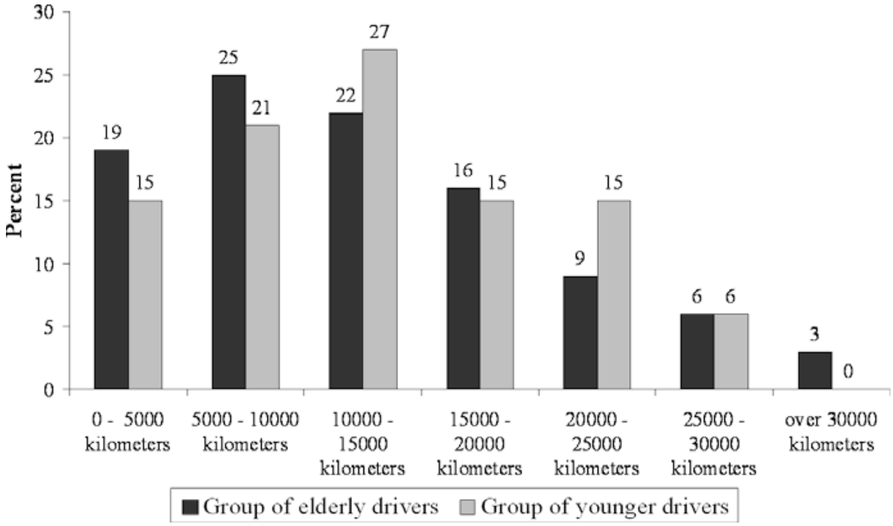

Fig. 2 Annual driving performance with the car in kilometers

Most of the probands in both groups use their car nearly every day. Approximately 63 % of the group of elderly drivers declared that they use their car daily and approx. 28 % stated that they use their car every two to three days. Approx. 70 % of the group of younger drivers use their car on a daily basis and approx. 15 % drive their car every two to three days. The frequency of using the car seems to be not very different according to both groups.

When being asked for an evaluation of their own driving performance in general approx. 38 % of the group of elderly drivers think that their own driving performance is good and approx. 60 % of the group of younger drivers evaluate their own performance as good. This shows, that the younger drivers seem to be more confident about their own driving performance. Approx. 15 % of the group of younger drivers strongly agree that they see themselves as very good drivers while none of the older probands strongly agree with this. This result is also intensified by the fact, that approx. 19 % of the group of elderly drivers would estimate their own driving performance as rather bad. Only about 3 % of the group of younger drivers estimate their performance in driving as rather bad (Fig. 3).

Only approx 50 % of the group of elderly drivers are open-minded about driver assistance systems while ca. 72 % of the group of younger drivers are. Approx. 19 % of the group of elderly drivers state that they are not open minded about driver assistance systems, while only approx. 3 % of the group of younger drivers state this. In both groups, the majority of the probands are open minded towards technology in general: about 60 % of the group of elderly drivers and approx. 88 % of the group of younger drivers state that they are open minded. The difference between the group of elderly and the group of younger drivers is also demonstrated by the result of the probands' open mindedness concerning technology in the car. Although the majority

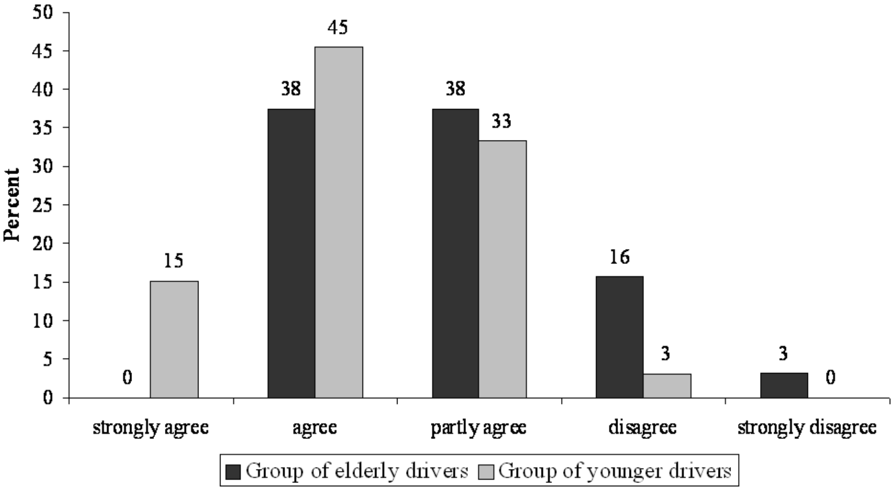

Fig. 3 Evaluation of the own driving performance in general

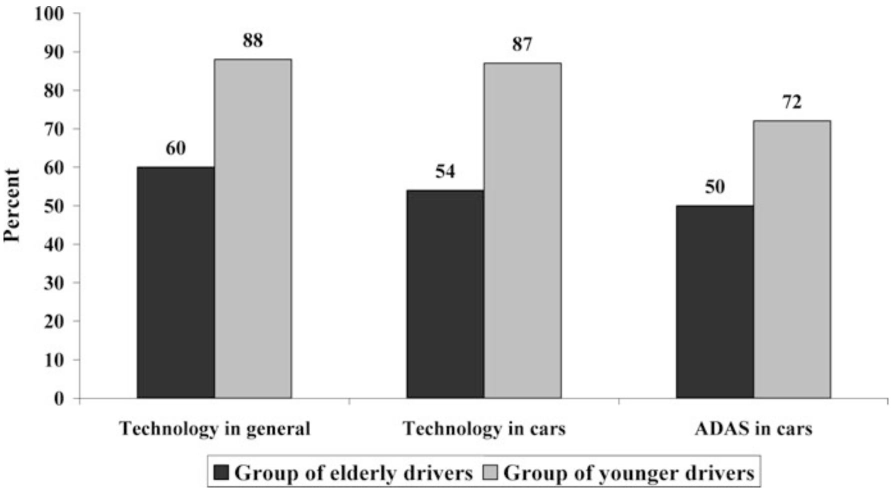

Fig. 4 Open mindedness concerning several technologies

of both groups is open minded about it (group of elderly drivers: approx. 54 %, group of younger drivers: approx. 87 %) there still is a difference of over 30 % between the groups. This demonstrates that although the majority of elder people seem to be open minded concerning technology in general, younger people are still more open minded about technology in the car and driver assistance systems (Fig. 4).

When asked about the functions of specific driver assistance systems, there were no huge differences between the two groups. 77 % of the group of elderly drivers and 75 % of the group of younger drivers think that a system that warns the driver against possible risks is helpful. A system that takes in dangerous situations is rated as helpful by 60 % of the group of elderly drivers and 53 % of the group of younger drivers. Driver assistance systems that take over individual driving tasks to support the driver are perceived as helpful by 50 % of the group of elderly drivers and 40 % of the group of younger drivers. 73 % of the group of elderly drivers and 72 % of the group of younger drivers think a driver assistance systems that gives information about certain facts while driving is helpful for the driver.

3.2 Results of the Workload Investigation

As mentioned above, the subjective evaluation of the workload was carried out by the probands via the NASA-TLX questionnaire after each maneuver they had driven.

The results of the evaluation of Active Steering tests showed that there is no significant difference between the group of elderly drivers, aged older than 64 years, and the group of younger drivers, aged between 35 and 50 years. The investigation showed that there are only minimal differences in the way the groups of older and younger drivers evaluated the workload indices for themselves for the tasks they were given. The evaluation of the individual workload indices referring to the dimensions Mental Demand, Physical Demand, Temporal Demand, Effort, Own Performance and Frustration Level also showed no significant distinctions in the subjective evaluations of both age groups.

Another result of the test drives was that the maneuvers according to their workload indices were not evaluated differently, regardless of being driven with a car that was equipped with Active Steering or a car that was not equipped with Active Steering. The answers of the NASA-TLX questionnaire showed that the maneuvers driven with the car equipped with Active Steering did not get better results according to the workload index that was indicated by the probands. Thus, probands driving the car with Active Steering were not less stressed during the maneuvers than they were during driving the maneuvers with the driver assistance systems turned off.

The results of the evaluation of Brake Assistant and advanced Brake Assistant show a slight difference between both groups. As expected the group of younger drivers was most stressed with ABS (Brake Assistant and advanced Brake Assistant switched off) and less stressed with Brake assistant and advanced Brake Assistant. But the results of the group of elderly drivers show the opposite. Brake Assistant was perceived as most stressful followed by advanced Brake Assistant. The probands evaluated ABS as least stressful.

3.3 Results of Driving Data

At the μ-split-full-brake-application without Active Steering it was noticeable that the group of younger drivers had a stronger tendency to countersteer than the group of elderly drivers. In the test runs without Active Steering the steering wheel angle

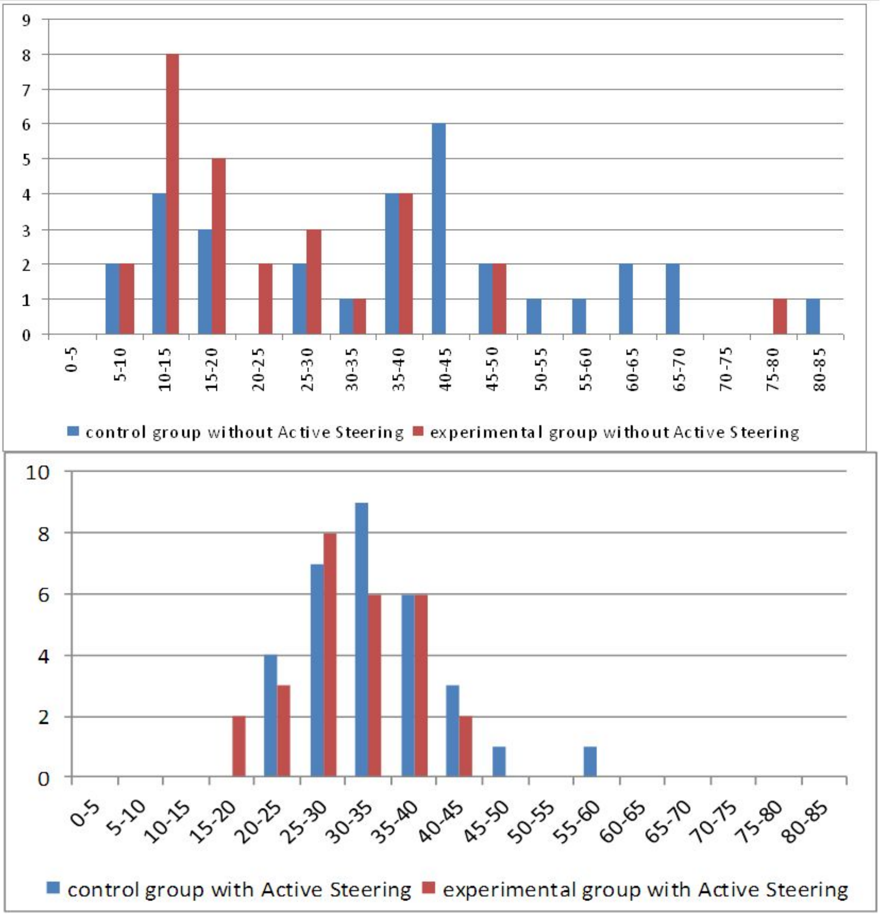

Fig. 5 Maximum turning wheel angle with and without Active Steering

of the group of elderly drivers was between 5 and 50°, with one outlier at 80°. The steering wheel angle of the group of younger drivers lies between 5 and 70°, with one value at 80–85°. In the test runs with Active Steering the range of the steering wheel angle was considerably smaller – between 15 and 50° within both groups, with one value at 55–60° (Fig. 5).

The test runs with ABS, Brake Assistant and advanced Brake Assistant provided remarkable differences in the stopping distance between the two groups. The average stopping distance in the group of younger drivers with ABS was 16.8 m, with Brake Assistant 16.6 m and with advanced Brake Assistant 16.4 m with average speed of approx. 57 km/h (Table 1).

In the group of elderly drivers the stopping distance with ABS was 18.1 meter, and with Brake Assistant and advanced Brake Assistant 17.0 meter each (average speed of approx. 57 km/h). Both Brake Assistant systems provided a shorter stop-

Table 1 Results ABS/BAS/advanced BAS, Group A (35 to 50 years)

	ABS	BAS	Advanced BAS
Speed target vehicle [km/h]	47.4	48.0	48.7
Speed own vehicle [km/h]	57.0	58.0	56.8
Distance to target vehicle before breaking [m]	9.2	9.1	8.9
Time to activate system [s]	0.34	0.09	0.12
Time to build up breaking pressure [s]	0.83	0.88	0.73
Max. breaking pressure [bar]	146.5	150.2	141.3
Stopping distance [m]	16.8	16.6	16.4
Distance to target vehicle after breaking [m]	3.8	3.9	4.2

Table 2 Results ABS/BAS/advanced BAS, Group B (65 to 80 years)

	ABS	BAS	Advanced BAS
Speed target vehicle [km/h]	45.9	45.2	43.8
Speed own vehicle [km/h]	57.7	57.6	57.0
Distance to target vehicle before breaking [m]	11.1	11.1	11.5
Time to activate system [s]	0.45	0.12	0.13
Time to build up breaking pressure [s]	0.88	0.67	0.79
Max. breaking pressure [bar]	131.5	138.6	124.9
Stopping distance [m]	18.1	17.0	17.0
Distance to target vehicle after breaking [m]	5.0	5.4	5.6

ping distance than ABS in the group of elderly drivers and the group of younger drivers as well. The average stopping distance of the elderly drivers was still longer than the one of the group of younger drivers. This applies to all three systems (Table 2).

For the group of younger drivers there are almost no differences between the result with and without BAS/advanced BAS. This can be explained with the fast reaction time and breaking pressure provided by the younger drivers.

In contrast to that for the group of the older drivers the time needed to build up the maximum breaking pressure is clearly shorter with BAS or advanced BAS than it is with ABS, which leads to an approx. 1 m shorter stopping distance.

3.4 List of Criteria and Recommended Procedures

One aim of this project was to develop a list of criteria that helps designing future active vehicle safety systems and to recommend procedures for political decisions. The developed criteria are meant as an addition to already existing criteria like guidelines and engineer standards for the development of active vehicle safety systems.

One result of the driving test was, that older people could often not activate the Brake Assistant or advanced Brake Assistant. This is directly linked to the activation trigger for those systems. Especially the reaction of the older drivers was not fast enough to trigger the Brake Assistant. In addition to that, the older drivers kept a bigger distance to the target vehicle. Therefore the breaking maneuvers were less critical than they were for the younger drivers.

Thus one criteria for the design of active vehicle safety systems is, that they should be developed to react independently of the drivers physical constitution. Active vehicle safety systems should be able to compensate physical disabilities intelligently and should therefore not rely on physical abilities of the drivers. This does not apply to older drivers only, but for example for younger people which are weaker or more anxious than the average as well.

The results of the μ-split-application show, that the active steering lead to more stable performance and less yawing of the car despite the different steering behavior of older and younger drivers. In the process more hesitant and more aggressive driving behavior is adjusted alike. This shows the importance of designing active vehicle safety systems with a certain tolerance towards the behavior of the driver.

The test drives further confirmed that the older drivers used a variety of compensation strategies to avoid critical situations. Examples for this are lower average speed and larger distances to the target vehicle. This shows the importance of the driver behavior for the road safety. In addition to that, the driver behavior should be considered more when designing active vehicle safety systems. To adopt the driver behavior it is inevitable to analyze the behavior of the target group. This can not be replaced through theoretical considerations only.

During the test runs it was obvious that most drivers were not able to successfully conduct a full-break-application with the first try when asked so. This shows the importance of initiatives that promote the improvement of driver behavior e.g. organizations that offer safety trainings for drivers. Further additional trainings within driver education would be possible, as they are already obligatory for professional truck drivers. The current available training could be supplemented by driving simulator trainings where critical situations could be trained without the risk of harming anybody. This is similar to the current changes in the truck driver training, which already may contain training sessions in driving simulators and could be linked to the introduction of the European driving license in 2013 which includes regular fitness to drive checks.

In addition the test runs showed, that the difference in driver behavior of older and younger drivers makes it necessary to develop active vehicle safety systems considering the driving behavior of different target groups. This should be integrated into guidelines and engineering standards that determine that in an early stage of the development of active vehicle safety systems tests should be carried out with an adequate sample to learn about the behavior of drivers.

4 Conclusion

In this paper a brief introduction about the project Evaluation of active vehicle safety systems and components in regard to their safety impact on elderly drivers was given. It also described the individual steps of the project. First the requirement analysis and its results were demonstrated. This analysis strongly suggested that elderly people account the car as the most desirable mean of transportation and that cars support elderly people in remaining their mobility. Within the described market analysis specific driver assistance systems were chosen for the test drives. As a next step the experimental design and the acceptance and workload investigation was presented.

The acceptance investigation showed that there are some differences in their answers concerning the groups of older younger drivers. The questionnaire suggested that younger persons are more open minded about technologies in general, technologies in the car and driver assistance systems. The results of the workload investigation showed that there is almost no difference between the stress level of the older and younger drivers. In addition to that no clear difference between the test runs with and without active vehicle safety systems have been found, the results of the workload investigation indicated that the probands were not relieved by the analyzed systems when driving the individual maneuvers, but were not additionally stressed by them either. The comparison of the subjective data with the objective driving data recorded during the test drives shows, that while there might be no difference between the two groups regarding their stress level, there is a difference regarding stopping distance and steering angle. With Braking Assistant and advanced Braking Assistant, the stopping Distance of the group of younger drivers was only slightly reduced ($< 0.4\,\mathrm{m}$), while it was clearly reduced for the group of elderly drivers. With the Active Steering the steering angle of both groups was adjusted to almost the same level.

At the end of the paper a short overview on the list of criteria and recommended procedures was given.

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Die Zukunft fest im Blick: Interdisziplinäre Innovationen

Klaus Henning, Esther Borowski

Zusammenfassung Damit Unternehmen weiterhin wettbewerbsfähig seien können sind sie in der vorherrschenden globalisierten, hoch technisierten und dienstleistungsorientierten Arbeitswelt zunehmend gefordert, ihre personale und organisationale Innovationsfähigkeit zu erhalten. Innovationsfähigkeit gilt als Schlüsselfaktor für den wirtschaftlichen Erfolg, denn nur wer sich langfristig am Markt mit neuen Ideen und anspruchsvollen, an Kundenwünschen orientierten Produkten bzw. Dienstleistungen bewährt, ist dauerhaft konkurrenzfähig und in der Lage, eine leistungsfähige Marktgröße zu etablieren. Die organisationale Fähigkeit, innovativ zu sein, hängt häufig weniger vom technischen Entwicklungsstand eines Unternehmens als vielmehr von seinen Humanpotentialen sowie seinen internen Prozessen und Strukturen ab. Deshalb ist ein ganzheitliches Verständnis notwendig, das den Innovationsbegriff nicht nur in seiner technischen, sondern auch in seiner sozialen und organisationalen Bedeutungsdimension umfasst. In diesem Artikel wird in die Thematik Innovationsfähigkeit eingeführt, sie in Kontext mit der Wettbewerbsfähigkeit von Unternehmen gesetzt und anhand zweier Praxisbeispiele diskutiert. Diese zeigen, dass die Bedingungen für Innovationsprozesse in einer globalisierten, sich stetig wandelnden (Arbeits-)Welt gestaltet werden müssen. Dabei ergeben sich zahlreiche Fragen, die sowohl im Hinblick auf die erforderliche Forschung als auch im Hinblick auf die praktische Umsetzung nicht hinreichend beantwortet sind.

Schlüsselwörter: Innovationsfähigkeit, Wettbewerbsfähigkeit

1 Einleitung

Zur Erhaltung ihrer Wettbewerbsfähigkeit sind Unternehmen in der vorherrschenden globalisierten, hoch technisierten und dienstleistungsorientierten Arbeitswelt zunehmend gefordert, ihre personale und organisationale Innovationsfähigkeit zu erhalten.

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Innovationsfähigkeit gilt als Schlüsselfaktor für den wirtschaftlichen Erfolg, denn nur wer sich langfristig am Markt mit neuen Ideen und anspruchsvollen, an Kundenwünschen orientierten Produkten bzw. Dienstleistungen bewährt, ist dauerhaft konkurrenzfähig und in der Lage, eine leistungsfähige Marktgröße zu etablieren.

Die organisationale Fähigkeit, innovativ zu sein, hängt häufig weniger vom technischen Entwicklungsstand eines Unternehmens als vielmehr von seinen Humanpotentialen sowie seinen internen Prozessen und Strukturen ab. Deshalb ist ein ganzheitliches Verständnis notwendig, das den Innovationsbegriff nicht nur in seiner technischen, sondern auch in seiner sozialen und organisationalen Bedeutungsdimension umfasst.

Unternehmen sind demzufolge gefordert, sowohl organisationale als auch personale Innovationspotenziale systematisch zu identifizieren und in marktfähige Produkte umzusetzen. Eine kontinuierliche Innovationsleistung kann jedoch nicht vorgegeben oder erzwungen werden. Kreativität und Innovation gibt es nicht auf Abruf. Innovationsfähigkeit entwickelt sich vielmehr durch den gezielten Einsatz innovationsförderlicher Methoden und Lernumgebungen, die kreatives Denken und Handeln sowie die Entwicklung von Neuem unterstützen.

2 Innovation – was ist das?

Was ist jedoch unter dem zentralen Begriff der Innovation zu verstehen? Innovationen werden als umfassende Veränderungen betrachtet, die technischen, personellen, organisatorischen Wandel bewirken. Sie werden wesentlich durch ökonomische und/oder ökologische Dimensionen bewertet. Der Begriff „Innovation" kann sich dabei auf das Resultat eines Prozesses (first level Innovation) oder auf den Prozess an sich (second level Innovation) beziehen. Innovationen sind nicht mit einfachen Zeichen, Daten und Informationen in Verbindung zu bringen. Sie sind weitaus mehr als das, und der Innovationsprozess beginnt erst mit dem nächsten Schritt.

Wissen, als zweckdienliche Vernetzung von verfügbaren Informationen, bildet das Fundament jeglicher Innovation (vgl. Abb. 1). Eine Innovation ist demnach die Kombination aus Wissen, und der Fähigkeit dieses Wissen anzuwenden. So beschreibt zum Beispiel BMW als Kernaufgabe des Innovationsmanagements:

> Unsere Aufgabe ist es, dem Kunden etwas zu geben, was er haben möchte, von dem er aber nie wusste, dass er es suchte und von dem er sagt, dass er es schon immer wollte, wenn er es bekommt. [GS08]

Das Innovationsmanagement beinhaltet als Maßnahmen sowohl zur Entwicklung als auch zur Bewertung von Ideen. Dabei liegen in der Gestaltung des Innovationsmanagements immense ungenutzte Potenziale. Während einige Unternehmen diesen Zusammenhang mit ihrem unternehmerischen Geschick instinktiv in Prozesse einfließen lassen, wählen andere den Weg der weitgehenden Standardisierung ihrer Innovationsprozesse. Oftmals bestimmt jedoch nicht die strategische Ausrichtung

Abb. 1 Innovationsprozess. Quelle: Eigene Darstellung in Anlehnung an North 1988

eines als wichtig und gut eingestuften Innovationsprozesses das Handeln, sondern Alltagsstress und Ressourcenbeschränktheit [SUH+03]. Die Bedeutung der betrieblichen Innovationsfähigkeit steht dabei nicht zur Debatte – auch nicht während der Krisenzeiten. Obwohl aber die meisten Unternehmen eine nachhaltige Innovationsfähigkeit als lebensnotwendig erkennen und entsprechende Strategien und Maßnahmen ableiten und implementieren [HS06], kennen die meisten die eigenen Innovationspotenziale und Erfolgsfaktoren nur selten oder lediglich „aus dem Bauch" heraus [Ott08].

3 Innovationsförderliche Methoden

Einer der entscheidenden Erfolgsfaktoren im Innovationsprozess sind die „kreativen Köpfe" im Unternehmen. Diese „kreativen Köpfe" benötigen jedoch in der Regel betriebliche Rahmenbedingungen, die es ihnen erlauben, ihre persönliche Charakteristika in die Arbeitswelt zu integrieren [HS08]. Dazu gehören u. a. Interesse, Hintergründe, Neugier, überheblichkeit, Bereitschaft zuzuhören, Zuversicht, Bescheidenheit. Dabei ist es nicht notwendig, dass die Chefs selbst Querdenker sind. Aber Chefs müssen Querdenken erlauben und Querdenker unterstützen.

Unternehmen können demnach die Mitarbeiter dann zu innovativem Verhalten motivieren, wenn diese die entsprechenden „Freiräume" finden und nutzen können. Eine Systematisierung des Innovationsprozesses für die Erreichung des erwünschten wirtschaftlichen Erfolgs reicht also nicht aus. *Disziplin und Kreativität* muss sich in einer Innovationsstrategie ergänzen. Es ist Aufgabe der Führungsebenen, die entsprechenden Rahmenbedingungen mit den passenden Maßnahmen zu gestalten. Die theoretische Unterstützung hierfür wird durch diverse Innovationsmodelle geliefert, wie z. B. dem SENEKA-Innovationsmodell (SIM), das den Anspruch hat, Unternehmen in die Lage zu versetzen, die eigenen Innovationspotenziale rechtzeitig zu erkennen, zu erfassen und zu nutzen und dadurch den nachhaltigen Wettbewerbsvorsprung in einer praktikablen Form zu ermöglichen [SUF02]. Kreativität braucht eine entspannte Wahrnehmung von Komplexität und Dynamik. Es braucht Rahmenbedingungen, die Querdenken fördern. Wie aber gestaltet man eine Organisation mit Querdenkern? Dazu braucht es ein Unternehmensklima, in dem man sich auch einmal zurücklehnen kann. Es werden Menschen benötigt, die einerseits unabhängig denken und handeln, andererseits innere Lähmung und Angst vor der eigenen Kreativität überwunden haben. Bei kreativen Führungskräften sind nach 10, 15, 20 Jahren sehr häufig massive Verschleißerscheinungen im Hinblick auf den Mut zur Kreativität zu beobachten [HH95]. Wenn man in Unternehmen nach den Ursachen dafür fragt, dann stößt man meistens darauf, dass die Menschen durch die Verhältnisse, unter denen sie das Unternehmen führen mussten, sehr viel eingesteckt haben. Wenn Menschen außen mit vielen Widerständen und ängsten umgehen, dann ist es ein Naturgesetz, dass im Inneren, aus der jeweiligen Biographie heraus, ängste hervorkommen, die in den individuellen Erfahrungen der Akteuren liegen. Und je mehr Verantwortung, je mehr Turbulenzen von außen auf die Person einwirken, desto mehr muss diese in seinem Inneren mit sich im Reinen bleiben oder werden. Hier liegt die eigentliche Ursache des so genannten „Burnouts“: Ich muss mit der Angst vor meiner eigenen Kreativität, wieder auszubrechen, mich wieder zu exponieren, wieder angefeindet zu werden, wieder nicht verstanden zu werden, im Reinen sein. In Zeiten sich globalisierender Ressourcenfindung und Innovationsprozessen durch die Nutzung des „Wissens der Vielen“ kommt dem Aufbrechen der Grundhaltung „Das haben wir schon immer so gemacht“ eine besondere Bedeutung zu. Etwas anders machen als bisher, heißt dabei aber auch, sich des Wissens anderer zu bedienen, die bisher in den Prozess nicht eingebunden waren.

Dazu muss man sich vergegenwärtigen, wo wir eigentlich kreativ sind (Abb. 2). Wir sind zum Beispiel zu einem Prozent in der Badewanne zu Hause kreativ, zu 5 % beim Essen und zu 8 % beim Fernsehen, zu 10 % auf der Geschäftsreise und zu einem Prozent, wenn wir Kreativitätstechniken im Büro anwenden. In der Pause bin ich zu 3 % kreativ, in Meetings, wo ich mich langweile, zu 9 %, am Arbeitsplatz zu 4 %, auf Reisen und in Ferien zu 12 %. Fazit: Innerhalb der Firma 24 %, außerhalb der Firma 76 % – und davon als größten Einzelbereich zu 25 % in der Natur.

Es kommt jedoch erst bei jedem tausendsten oder fünfhundertsten Gedanken zu einer betriebsbrauchbaren Idee (Abb. 3). Und um erfolgreich am Markt zu sein, brauche ich sehr viele Ideen. Der wirtschaftliche Erfolg von Innovationen hängt letztendlich davon ab, ob diese als erfolgreiches Produkt bzw. Systemlösung auf dem Markt bestehen können. Die beste betriebliche Innovation kommt entweder auf den Markt, weil sie von Kunden nachgefragt wird, oder in die Schublade, bis die Nachfrage kreiert oder plötzlich unter anderen Umständen wieder entdeckt wird.

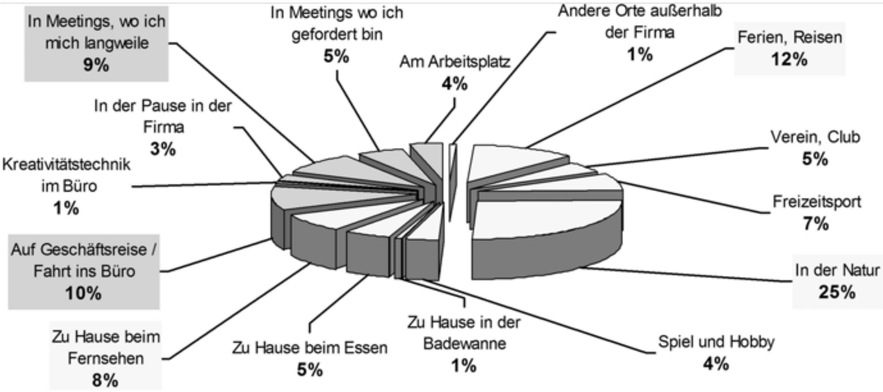

Abb. 2 Wo entstehen neue Ideen [Ber93]

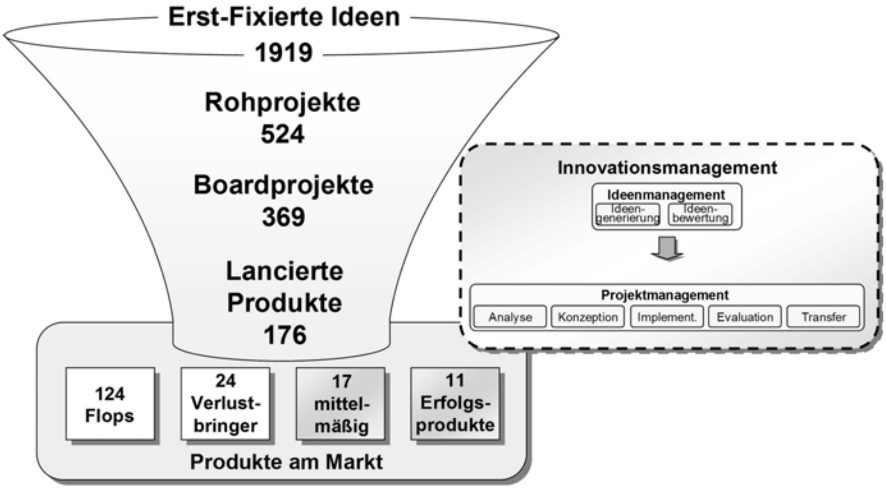

Abb. 3 Der Innovationswolf [Ber93]

Wenn man nun nach Merkmalen fragt, wie Kreativitäts- und Innovationsprozesse organisiert und gesteuert werden können, dann ist die Voraussetzung dafür, dass das Unternehmen selbst im ständigen Wandel ist – und zwar unter Beteiligung aller im Betrieb. Innovation bedeutet immer Bruch mit der Vergangenheit und das Umstoßen lieb gewordener Gewohnheiten. Dieses Verständnis setzt jedoch eine entsprechend gewachsene Unternehmenskultur voraus. Ein kreativer Innovationsprozess zeichnet sich demnach als beteiligungsorientierter Change-Prozess aus, der auf einem H-O-T Ansatz basiert [Bra03], der zuerst den Menschen (Human), dann die Organisation und im dritten Schritt die Technologie berücksichtigt. Dabei erzwingen innovative Technologiefusionen neue Wege beteiligungsorientierten Arbeitens und Lernens in global verteilten Teams [HS06].

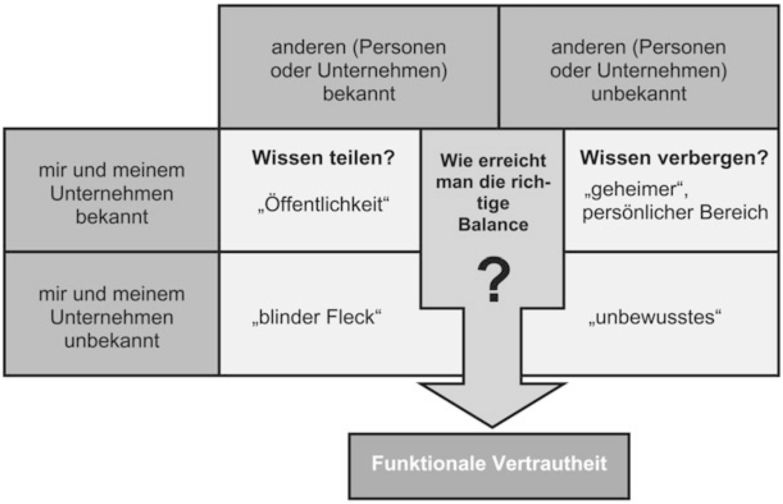

Abb. 4 Funktionale Vertrautheit [HHB06]

Unabhängig von der Frage, wo Ideen entstehen, ist es Aufgabe des Unternehmens, die Mitarbeiter in Bezug auf die notwendigen Kompetenzen innovationsfähig zu machen. Mitarbeiter müssen in die Lage versetzt werden, ihr Fachwissen unter hohem Arbeits- und Wettbewerbsdruck auszubauen und Lösungen für zunehmend komplexe Probleme zu entwickeln. Eine nachhaltige Kompetenzentwicklung muss diese Rahmenbedingungen berücksichtigen und die Mitarbeiter handlungsfähig machen. Arbeiten und Lernen wachsen dabei zunehmend zusammen – auf allen Ebenen [LMSS07]. Individuelles Lernen, das Lernen in Teams, in der Organisation und in Netzwerken wird existenzieller Bestandteil der (Zusammen-) Arbeit [BFH08, Ise97, Ung98]. Die Verknüpfung von Arbeits- und Lernprozessen im betrieblichen Kontext fordert alle Beteiligten: Wissenschaft und Praxis, Unternehmer und Mitarbeiter.

Bildung und Wissen sind die entscheidenden Standortvorteile Deutschlands und diejenigen Produktionsfaktoren, die am schlechtesten von anderen imitiert werden können. Deshalb ist Wissensmanagement ein strategischer Erfolgsfaktor für den Standort Deutschland. Ein entscheidender Punkt ist dabei, in bestimmten Phasen Wissen zu teilen und in (globalen) Netzwerken kreativ zu sein. Es muss eine Balance zwischen den Polen „Wissen teilen" und „Wissen verstecken" gefunden werden [HHB06], (Abb. 4). Wer immer alles Wissen teilt, kommt selten zu einem Wettbewerbsvorteil, das gleiche gilt aber auch für denjenigen, der immer alles Wissen versteckt.

Hieraus entsteht eine Innovationsdynamik, die als „Funktionale Vertrautheit" bezeichnet wird. Diese Vertrautheit in Unternehmen zu entwickeln und zu fördern, kann mit Methoden des systemischen Change Managements ermöglicht werden (vgl. www.osto.de, [HS10]).

Diese Innovationsdynamik bedarf eines erhöhten Durchhaltevermögens des Individuums. Insbesondere müssen eigene Ziele mit Ausdauer und Beharrlichkeit verfolgt werden, um den zur Erhaltung der Wettbewerbsfähigkeit nötigen Vorsprung zu erreichen. Mit Beharrlichkeit müssen eigene Produkte überarbeitet werden und die Ausdauer aufgebracht werden, sich nicht rasch zufrieden zu geben.

Innovationsprozesse für den Standort Deutschland erfordern auch neue Lern- und Arbeitsprozesse. Hierbei müssen interdisziplinäre Ansätze in den Vordergrund gerückt werden, die durch eine Bündelung verschiedener Sichtweisen und Zugänge den komplexen Anforderungen gerecht werden. Die Verschiedenheit und Vielfalt der Beteiligten muss in diesem Zusammenhang als Ressource wahrgenommen und zielführend genutzt werden. Das Zusammenwirken von Anwendern, Betreibern und Entwicklern von Technik spielt dabei eine bedeutende Rolle [Ung00]. Dies erfordert neue Methoden der Produkt- und Prozessgestaltung insbesondere bei der Verknüpfung von IT-Technologien mit klassischen Technikfeldern. Beispielhaft sei hier die Entwicklung eines dezentralen Heizungspumpensystems genannt. Dieses dezentrale Pumpensystem setzt auf mehrere Miniaturpumpen an den Heizflächen bzw. Heizkreisen anstelle der Temperaturregulierventile. Eine zentrale Steuereinheit mit modernster Computertechnik erkennt den Wärmebedarf der einzelnen Räume und versorgt die Heizkörper individuell mit Hilfe der Miniaturpumpen [wil, spe10].

Interdisziplinäre Zusammenarbeit erfordert vielfältige soziale, personale und methodische Kompetenzen, welche schon in der Ausbildung erworben werden müssen. Fachübergreifende Kompetenzen müssen in Ausbildung und Studium immer noch wesentlich mehr Gewicht erhalten. Neben Schulen stellen hierfür Fachhochschulen und Universitäten einen wichtigen Baustein dar. Hier müssen konsequent berufsübergreifende Ausbildungsabschnitte, Lehrveranstaltungen und Projektarbeiten integriert und umgesetzt werden, die am zukünftigen beruflichen Handeln orientiert sind. Im Folgenden werden nun zwei Beispiele vorgestellt, die solche interdisziplinären, ganzheitlichen Innovationsansätze verdeutlichen sollen.

4 Interdisziplinäre Innovationsprojekte – Beispiele

4.1 Internationales Monitoring zur Innovationsfähigkeit (IMO)

Unter dem Motto *Lernen im Prozess der Arbeit* untersucht das ZLW/IMA der RWTH Aachen im Auftrag des BMBF innerhalb des Projektes *Internationales Monitoring* innovative Lösungsansätze zu identifizieren, die zu einer Steigerung des Innovationspotentials in einer modernen, sich ständig wandelnden Arbeitswelt beitragen können. Eine Basis hierfür bilden Fördermaßnahmen des BMBF in diesem Feld, die alleine in den Jahren 2001 bis 2010 mehr als 50 Mio. EUR umfasst haben. Trends und Entwicklungen wurden innerhalb von Trendstudien, einer internationalen Online-Umfrage, Expertenarbeitskreisen und durch Identifizierung von Best-Practice Beispielen erkannt und den drei Zukunftsclustern *Arbeiten 2020*, *Lernen*

2020 und *Kompetenzen entwickeln 2020* zugeteilt. Das Zukunftscluster Arbeiten 2020 rückt den Unternehmer als Innovationstreiber in den Fokus der Betrachtung. Der Export wissensintensiver Dienstleistungen, innere und äußere Mobilität der Unternehmen und die Fähigkeit, Einzigartigkeit zu erreichen, werden ebenfalls benötigt, um zukünftigen Anforderungen gerecht zu werden. Das Zukunftscluster *Lernen 2020* adressiert Lernen mit weltweiter Vernetzung und eine Entwicklung von virtuellen Netzwerken zum Normalfall. Die digitale Generation wächst stetig heran und fordert adäquate Lehr- und Lernkonzepte zur Unterstützung selbstgesteuerter und arbeitsplatznaher Lernprozesse. Im Rahmen des Zukunftsclusters Kompetenzen entwickeln 2020 wurde festgestellt, dass hybride Systeme zur Kompetenzentwicklung sich in Zukunft weitläufig etablieren werden. Auch die Entwicklung neuer Arbeitstrukturen für die digitale Generation und Synergien zwischen jüngeren und älteren Arbeitnehmern werden benötigt, um die Kompetenzen von Mitarbeitern als Innovationsträger weiter zu entwickeln. Zusätzlich müssen künftige Innovationsprozesse in Kooperation mit horizontalen und vertikalen Netzwerken, Universitäten, Start-Ups, Zulieferern und Konkurrenten entstehen, um sozial-, konsumenten- und kundenorientiert ausgerichtet zu sein.

Die genannten Trends und Entwicklungen innerhalb der drei Zukunftscluster *Arbeiten 2020*, *Lernen 2020* und *Kompetenzen entwickeln 2020* haben eines gemeinsam: Sie sind Konsequenzen bzw. Reaktionen auf die globale Tendenz hin zu mehr Dynamik und Komplexität (Dynaxity) im Berufs- genauso wie im Privatleben vieler Menschen. In Zeiten der weltweiten Wirtschaftskrise wird es in Zukunft wichtig sein, Arbeitssysteme so zu gestalten, dass langfristige Innovationsfähigkeit erhalten bzw. ausgebaut werden kann. Um dies erreichen zu können, müssen die genannten Trends und Entwicklungen weiterhin beobachtet und sinnvoll genutzt werden. Nur so können tiefgreifende Veränderungsprozesse auf allen sozioökonomischen Ebenen erfolgreich bewältigt werden.

Verbindet man diese Trends zu Arbeiten, Lernen und Kompetenzen mit den Zukunftsstudien zum Standort Deutschland zeichnen sich drei weitere für Deutschland und Europa in den nächsten ein bis zwei Jahrzehnten Entwicklungen ab, die sich unter den Schlagwörtern „Mangelware junger Mensch“, „Enabled by Germany“ durch Deutschlands „Hidden Champions“ und der global-regionale „Homo Zappiens“ zusammen fassen.

Mangelware junger Mensch

Von „Mangelware junger Mensch“ lässt sich sprechen, da selbst wenn eine positive Tendenz bei der Zunahme von Geburten einsetzt, wird sich ein positiver Knick in der Geburtenrate erst in ca. 20 Jahren am Arbeitsmarkt auswirken können [BBSLW02]. Bis dahin müssen wir mit den gegebenen demografischen Gesellschaftsbedingungen leben: Immer weniger Menschen im jungen und mittleren Alter stehen einer immer größer werdenden Anzahl von Menschen im Rentenalter gegenüber [BBSLW02], die eine immer längere Lebenserwartung genießen können [Sta06]. Daraus ergeben hauptsächlich sich zwei Konsequenzen: Zum Einen werden ältere Menschen tendenziell länger arbeiten können und müssen [Rür03] (vgl. Herzog-Kommission 2003). Hier reicht allein das Konzept „Rente mit 67“

nicht aus (vgl. EU Kommission 2009), sondern es bedarf neuer Ansätze für eine alterns- und altersgerechte Arbeitspolitik [Kis06], die die Komponenten Altern, Gesundheit und Kompetenzentwicklung berücksichtigt [Hen09]. Zum Anderen muss Deutschland ein Land mit einer hervorragenden Immigrationskultur werden. Vorbild dafür sind klassische Einwanderungsländer wie Kanada und Australien [Cam04]. Um den Standort Deutschland für ausländische Hochqualifizierte interessant zu machen, muss dem guten ersten Schritt ein „Land der Ideen" (vgl. Bundesregierung 2006) zu etablieren, der zweite Schritt zu einem „Land der Wertschöpfung" [Cla06] folgen.

Außerdem muss es denjenigen, die sich entschlossen haben nach Deutschland zu kommen, einfacher gemacht werden, ein soziales Netzwerk aufzubauen [Ber09].

Enabled by Germany

Deutschland wird den Titel „Exportweltmeister" nicht verteidigen können. Jedoch hat Deutschland dadurch die Chance in zunehmendem Maß ein „Enabler" zu werden, der anderen Ländern hilft, ihre eigenen Produktions- und Dienstleistungsprozesse zu gestalten. Durch dieses Umdenken kann Deutschland sich erstens neue Märkte und Abnehmer erschließen und zweitens einer neuen Art von Hilfestellung leisten. Denn das Beste für die Entwicklungsländer ist es, wenn sie ihren Eigenbedarf an Produkten und Dienstleistungen eigenständig herstellen und produzieren können. Für die Entwicklungsländer bestünde so die Möglichkeit die eigene Versorgung unabhängig von den Industriestaaten sicherzustellen.

Deutschland sollte demnach diesen kombinierten Produktions- und Dienstleistungssektor im Sinne seiner zukünftigen wirtschaftlichen Entwicklung für sich entdecken [BD06] und sich als globaler Dienstleister engagieren. Zukünftig werden sich die Sektoren Produktion und Dienstleistungen immer schwerer voneinander trennen lassen [Bry09]. Zwei Bereiche können im Fokus dieser Anstrengungen stehen, die Vermarktung von Bildung, Aus- und Fortbildung „Made in Germany" sowie die Stellung als internationaler Partner für kombinierte Produktions- und Dienstleistungsprozesse. Hier könnte der Begriff „Made in Germany" ersetzt werden durch den Slogan „Enabled by Germany". Die Voraussetzung für ein erfolgreiches Auftreten auf dem Markt der Dienstleistungen ist, dass deutsche Unternehmer mit ihren Mitarbeitern mobil sind und auf den Kunden im Ausland zugehen [MB05]. Das duale Ausbildungssystem, gewerblich-technische und Handwerksausbildungen sind prädestiniert, um weltweite Bestseller zu werden.

Der zweite Fokus „Enabled by Germany" bezieht sich im besonderen Maße auf die Bereiche Forschung, Entwicklung und Design. In vielen Nischen der Wirtschaft haben sich deutsche Unternehmen einen Platz als Weltmarktführer erarbeitet. Denn eigentümergeführte Unternehmen, die in Deutschland 75 % aller Arbeitsplätze stellen (vgl. IfM Bonn 2006), agieren heute schon in großem Maß erfolgreich in globalen Strukturen [Hun03] und treiben Innovationsprozesse voran [Hen09]. Von dieser Art Unternehmen gibt es eine große Anzahl. Allein 75 deutsche Zulieferer produzieren technologisch innovative Teilkomponenten für das Luft- und Raumfahrtunternehmen Boeing [Boe08] – Deutschland ist voll von weltweit besten Technologie-Komponenten [Sim07]. Was heißt dies in letzter Konsequenz? Wir müssen unser

Privileg, zu einem der reichsten Länder der Erde zu gehören, durch Fleiß und Mehrarbeit an den Stellen weiterentwickeln, an denen die anderen Länder (noch) nicht so weit sind, dass sie es selbst machen könnten. Nur da, wo wir wirklich besser, geschickter, flexibler und innovativer als andere sind, sollten wir die zugehörigen Arbeitsplätze in Deutschland behalten.

Der global-regionale Homo Zappiens

Die fortschreitende Digitalisierung und die kontinuierliche Verbreitung von Internetanschlüssen [Sch07] gebiert eine neuartige globale Intelligenz. Für Mitglieder der digitalisierten Generation ist es bereits nach wenigen Lebensjahren selbstverständlich, sich im Internet zu bewegen, dort einen großen Teil seiner Lebenszeit zu verbringen und Freundschaften in Form virtueller sozialer Netzwerke zu pflegen. So entwickelt sich eine neue Art von Lebensqualität im Sinne eines Homo Zappiens [VV08].

Seit dem das Internet untrennbar mit dem alltäglichen Leben verbunden ist, wurden von den Nutzern neue Strategien entwickelt, wie sie mit der Vielfalt an Informationen und Wissen effizient und ergiebig umgehen können [Hen09]. Die Welt rückt durch den technischen Fortschritt zusammen. Tägliches Kommunizieren mit Freunden über weite Distanzen hinweg, der Austausch von Ideen und die gemeinsame Arbeit an einem Projekt über die Grenzen von Kontingenten hinweg, wie z. B. der Entwurf und die Weiterentwicklung von Open-Source Software, [HK09] stellen heutzutage kein Problem mehr dar, da Blogs und Wikis zum Standard der alltäglichen Kommunikation gehören. Im Rahmen dieses Digitalisierungsprozesses wird das Bedürfnis nach räumlicher Geborgenheit in regionalen Milieus paradoxerweise extrem zunehmen [MK96]. Die einzelnen Regionen wie beispielsweise Oberschwaben oder das Inntaldreieck, die Euregio Aachen oder Zwickau, das Vogtland oder die Lausitz werden für die Identität des Menschen wieder an Bedeutung gewinnen – angesichts der „Verlorenheit" im globalen Raum der zappenden Internet-Welt.

Um den zuvor genannten Trends begegnen zu können, wurden verschiedene Projekte unter den Schlagwörtern, Beteiligungsqualifizierung [Bit91], Partizipation & Empowerment, Gestaltung von Dienstleistungsprozessen und die aktive Mitgestaltung technischer Innovationsprozesse durchgeführt. Letzteres soll an zwei weiteren Beispielen verdeutlicht werden.

4.2 Technische Innovationsprojekte zu LKW-Konvois und zum Rettungsdienst

Der interdisziplinäre Ansatz des Innovationsmanagements zeigt sich in besonderer Weise in komplexen technischen Innovationsprojekten. Zwei Beispiele, die an der RWTH mit zahlreichen industriellen Partnern durchgeführt werden bzw. wurden, sollen dies verdeutlichen.

Abb. 5 Lkw-Konvoi auf der Autobahn. Quelle: ZLW/IMA der RWTH Aachen

4.2.1 Automatisierte Lkw-Konvois auf Autobahnen

Seit 2001 untersucht die RWTH Aachen mit zahlreichen industriellen Partnern wie MAN, Wabco, Iveco mit einem Gesamtaufwand von mehr als 10 Mio. EUR mit Förderung des BMWI den Einsatz von Lkw-Konvois auf Autobahnen zum Ziel (vgl. Abb. 5). Ausgehend von interdisziplinär entwickelten und evaluierten Szenarien, wurde die nötige Technik entwickelt und schrittweise erprobt und angepasst. Dabei wurden mit Hilfe von realen und virtuellen Fahrversuchen – unter Einsatz von Lkw-Versuchsträgern und eines Lkw-Fahrsimulators – die Auswirkungen und Effekte auf den Verkehr analysiert. Während der Entwicklung und Untersuchungsreihe wurde systematisch die Akzeptanz der Systeme bei den Lkw-Fahrern, den Spediteuren und den anderen Verkehrsteilnehmern erhoben und die Belastung bei den Lkw-Fahrern ermittelt. Als bisheriges Ergebnis wurde mit vier im 10m Abstand gekoppelten Lkw‘s auf Teststrecken mehr als 60 Tage gefahren und im öffentlichen Verkehr über 3000 km zurückgelegt [ver09].

4.2.2 Telematisch unterstützter Rettungsdienst

Als zweites Beispiel sei das Forschungsprojekt Med-on-@ix genannt – das zurzeit umfangreichste Forschungsprojekt im deutschen Rettungsdienst (vgl. Abb. 6). Hier wird der Einsatz von aktueller Telekommunikationstechnik in der Notfallrettung erprobt. Zentrales Vorhaben innerhalb des Projekts ist die Schaffung einer Telenotarzt-Zentrale, die mit hochqualifizierten Notärzten, den sogenannten Tele-Notärzten, besetzt ist.

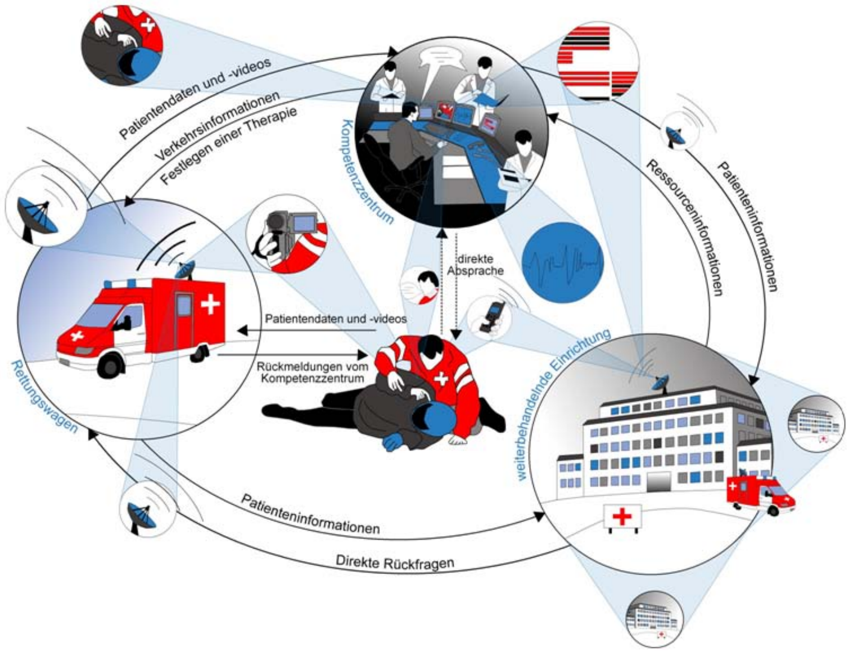

Abb. 6 Telemedizin im Rettungsdienst [SBR+09]

Von der Einsatzstelle und aus dem Rettungswagen werden Daten, Messwerte und Live-Videos direkt an die Telenotarzt-Zentrale übertragen. Der Notarzt in der Telenotarzt-Zentrale beurteilt die Lage und die Werte. Bei Bedarf holt er zusätzliche Informationen, z. B. bei der Vergiftungszentrale oder in Datenbanken ein und unterstützt das Rettungsteam vor Ort schließlich beim Einsatzablauf und bei der Behandlung des Patienten. Die Konzepte sind somit orientiert an einheitlichen Qualitätsmaßstäben und medizinischen Leitlinien. Das Forschungsprojekt Med-on-@ix könnte somit in Zukunft eine hochqualifizierte notärztliche Hilfe jederzeit zugänglich machen, die Qualität der Patientenversorgung im Rettungsdienst verbessern und die Rettungsdienst-Einsätze effizienter gestalten [med].

5 Offene Fragen

Die exemplarisch vorgestellten interdisziplinären Innovationsprojekte zeigen die Bedingungen, unter denen Innovationsprozesse in einer globalisierten, sich stetig wandelnden (Arbeits-)Welt gestaltet werden müssen. Dabei ergeben sich zahlreiche Fragen, die sowohl im Hinblick auf die erforderliche Forschung als auch im Hinblick auf die praktische Umsetzung nicht hinreichend beantwortet sind. Einige dieser Fragen seien abschließend gestellt.

- Wie kann ein Arbeiten-im-Alter-Modell aussehen?
- Bei notwendiger und gewünschter Steigerung der Immigranten wie wollen wir Diversitymanagement verstehen und anwenden?
- Wie gestaltet sich Mitarbeiterqualifizierung in Teams, die über die Welt verstreut sind und aus den unterschiedlichsten Kulturen und sozialen Bedingungen kommen?
- Wie sieht Partizipation und Beteiligungsqualifizierung aus, wenn das Internet als hauptsächliches Kommunikationsmedium verwendet wird? Wie werden in diesem Zusammenhang Blogs, Foren und Wiki die Unternehmenskulturen nachhaltig verändern können?
- Wie sind die Kompetenzen des Homo Zappiens zu bewerten? Wie können diese weiterentwickelt werden? Welche sozialen Spannungen werden dadurch neu entstehen und wird diese Entwicklung die Arbeits- und Verhaltensstrukturen in den Betrieben beeinflussen?

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Agile Werte im Innovationsmanagement

Ingrid Isenhardt, Max Haberstroh, Christian Tummel, Ralph Kunze, Marina Scheiff, Eckart Hauck

Zusammenfassung Unternehmen sind im globalisierten Markt einer Komplexität und Dynamik ausgesetzt, die sich nicht reduzieren lässt. Die dadurch entstehenden Turbulenzen stellen nicht unbedingt eine Gefahr für ein Unternehmen dar, sondern können im Gegenteil auch als Quelle zur Steigerung der Innovationsfähigkeit dienen. Um dies zu gewährleisten müssen die unternehmensinternen Prozesse so moduliert werden, dass sie auch in turbulenten Kontexten bestehen können. Dazu müssen sich Unternehmen und ihre Mitarbeiter ihren eigenen Strukturen und Prozessen bewusst werden und lernen diese agil zu gestalten. Zur Unterstützung benötigen Unternehmen Werkzeuge, die es ihnen erlauben, die eigene Situation zu analysieren und Möglichkeiten zu identifizieren, wie bislang noch nicht ausgeschöpfte Potenziale nutzbar gemacht werden können. Der Beitrag von Isenhardt et al.: „Agile Werte im Innovationsmanagement" stellt Grundlegende Überlegungen vor, wie die aus der agilen Softwareentwicklung stammenden Agilen Prinzipien Produzierenden Unternehmen aus dem Anlagenmaschinenbau dabei helfen können verborgene Innovationspotenziale zu aktivieren.

Schlüsselwörter: Innovationsfähigkeit von Unternehmen, Smarte Innovation, Product Lifecycle Management

1 Einleitung: Von der Umwelt als Störgröße zur Umwelt als Chance

Das klassische hierarchische Steuerungssystem, bei dem Planbarkeit, Kontrollierbarkeit und Sicherheit oberste Priorität haben, ist immer noch in vielen Unternehmen wirksam, während Umgangsstrategien mit Komplexität wie Flexibilität, Im-

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provisationskunst und Selbststeuerung – kurz: die agilen Prinzipien – zwar propagiert, aber nicht nachhaltig implementiert sind. Obwohl Wissenschaftler und Manager, die sich mit Organisationsentwicklung beschäftigen, längst ein Problembewusstsein dafür haben, ist und bleibt es eine große Herausforderung für Organisationen und ihre Mitglieder, in einem komplexen, vernetzten und dynamischen Umfeld erfolgreich handlungs- und damit wettbewerbsfähig zu bleiben. Die Suche nach Wegen zur Bewältigung von Komplexität hat in verschiedenen wissenschaftlichen Disziplinen zu Ansätzen geführt, die sich mit weitgehend unberechenbaren Wirkungsstrukturen und prozessen auseinandersetzen (z. B. Feld- und Systemtheorie, Autopoiese- und Chaostheorie, Konstruktivismus). Seit den 1990er Jahren versucht man verstärkt, diese Erkenntnisse für das Management von Organisationen nutzbar zu machen. Allerdings trifft dies, wie einleitend angesprochen, in Produktionsunternehmen noch häufig auf etablierte Struktur-, Führungs- und Verhaltensmuster, die zumeist unter statischeren Bedingungen entstanden sind. Es hat sich häufig ein „technokratisch-bürokratisches“ Management mit einer horizontal und vertikal ausgeweiteten Arbeitsteilung, „objektivierten“ und präzise vorgeschriebenen Kommunikationswegen und genau definierten Zuständigkeitsinstanzen entwickelt. Diese dem jeweiligen Unternehmensmodell zugrunde liegenden Metaphern haben einen erheblichen Einfluss auf die Gestaltung der Prozesse und die Art der innerbetrieblichen Zusammenarbeit. Wird ein Unternehmen von Führungskräften und Mitarbeitern wie eine Maschine betrachtet, überwiegen einheitliche Vorschriften. Zentrale Entscheidungen werden als Voraussetzung für Arbeits- und Handlungsfähigkeit gefordert. Es überwiegt die Forderung nach Spezialisierung der Mitarbeiter und Abteilungen und einer Standardisierung ihrer Arbeit – sicher auch, weil Fehlerzuweisungen und Absicherungsstrategien in solchen Gebilden besser gelingen. Die Aufgaben der einzelnen Abteilungen und Mitarbeiter greifen „wie Zahnräder“ ineinander – Redundanzen und überlappungen sind eher unerwünscht, weil ineffizient. Die Umwelt wird vor allem von Instanzen, die nicht im direkten Kundenkontakt stehen, häufig als „Störgröße“ betrachtet. Auf diese Weise wird versucht, die Komplexität im Unternehmen zu reduzieren und den kreativen Umgang mit der Umwelt und ihren Anregungen an die zuständigen Abteilungen – Vertrieb und Marketing – zu delegieren. Dagegen stehen Modelle, die Unternehmen als lebende, dynamische Systeme begreifen, welche die Außenkomplexität im Inneren abbilden [Ash63], Austauschprozesse mit ihr als Innovationsquelle erkennen und kreative Redundanzen nutzen. Im Gegenzug akzeptieren sie, dass Steuerbarkeit nur bedingt gegeben ist. Unternehmen, denen ein solches organisches Organisationsverständnis zu Grunde liegt, haben das Potenzial, die Umweltdynamik für sich zu nutzen und so ihre Innovationsfähigkeit zu steigern [Ise94]. Im Folgenden wird aufgezeigt, wie durch solche komplexitätsorientierten Prinzipien Innovationsimpulse – im Sinne von Produkt- und Prozessinnnovation – erfolgreich im Unternehmen gesetzt werden können und welche Rolle insbesondere agile Werte dabei spielen.

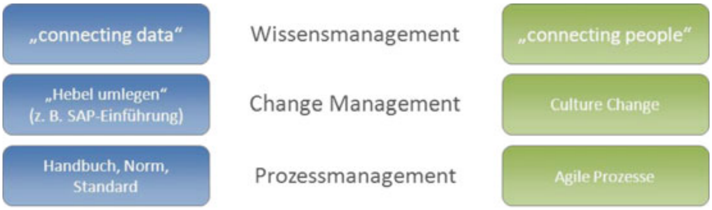

Abb. 1 Vereinbarung traditioneller und agiler Strategien

2 Situationsangepasste Strategien als Schlüsselkompetenz

Eine strikte Trennung zwischen starren bzw. mechanistischen und dynamischen Systemen ist nicht zielführend. Regeln, Standards und Tools sind auch für Organisationen in turbulenten Umgebungen für die Strukturierung und das Steuern grundlegender Prozesse sinnvoll. Um mit steigender Komplexität und Dynamik umzugehen, sind jedoch ergänzende Strategien notwendig. Die Auswahl situationsangepasster Strategien stellt eine Schlüsselkompetenz für Unternehmen und ihre Mitarbeiter dar, wenn sie in turbulenten Kontexten erfolgreich sein und bleiben wollen [IP09]. Dementsprechend geht es darum, traditionelle und agile Werte zu verbinden und damit Raum für Innovationen zu schaffen. Abbildung 1 stellt beispielhaft unternehmerische Strategien vor, die grundsätzlich die beiden vorgestellten Metaphern/Managementperspektiven repräsentieren.

Bei der Gegenüberstellung geht es weniger um ein Entweder-oder als vielmehr um ein Sowohl-als-auch beider Ansätze. Es können nämlich beide – abhängig vom Kontext – zum Erfolg eines Unternehmens beitragen. Das Sammeln, Zusammenführen und Aufbereiten quantitativer Daten beispielsweise ist natürlich ein wesentlicher Bestandteil eines erfolgreichen Wissensmanagements; es kann jedoch nicht die Vernetzung von Mitarbeitern, Kunden und Partnern ersetzen, durch die der Austausch impliziten Wissens gefördert werden kann. Ebenso wenig kann auf die unternehmensweite Einführung neuer Techniken verzichtet werden; der damit einhergehende kulturelle Wechsel bedarf aber mindestens genauso viel Beachtung. Das Gleiche gilt für Handbücher, Normen und Standards, die einen unumstrittenen Beitrag zur erfolgreichen Steuerung von Unternehmen leisten; um Platz für Innovationen zu lassen, müssen die Prozesse jedoch agil gestaltet und einfallsreiche Wege trotz oder sogar jenseits der Normen und Standards ermöglicht werden.

Mit steigender Komplexität und Dynamik – hier mit dem Kunstwort „Dynaxity“[1] bezeichnet – wächst jedoch die Wichtigkeit der Einbeziehung agiler Werte, um ein Unternehmen überhaupt steuern zu können. Dementsprechend gelten die Werte des Agilen Manifests, dass Individuen und Interaktionen wichtiger sind als Prozesse und Werkzeuge, funktionierende Produkte eine höhere Bedeutung haben als umfassende Dokumentation, die Zusammenarbeit mit dem Kunden höher einzuschätzen

[1] Siehe Henning [Hen99]. Das Kunstwort Dynaxity ist eine Zusammensetzung aus dynamic und complexity.

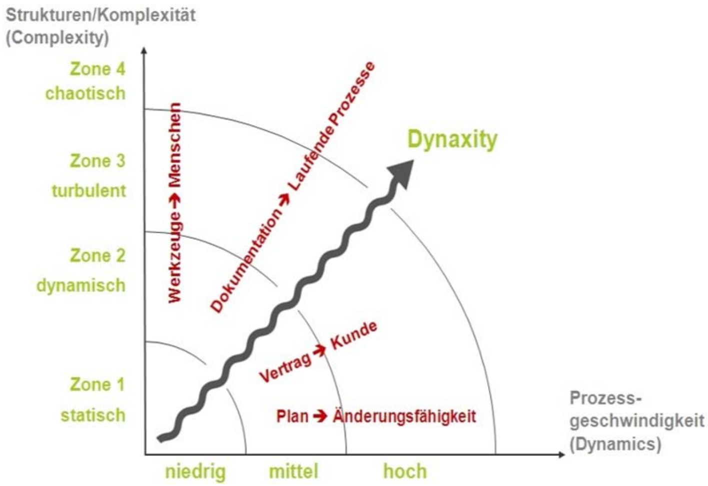

Abb. 2 Die organisationale Umwelt wird zunehmend komplex und dynamisch, nach Henning et al. 2000

ist als Vertragsverhandlungen und dass die Fähigkeit, auf Veränderung zu reagieren, wichtiger als das Befolgen eines Plans ist – umso mehr, je dynamischer und komplexer die Umwelt ist, in der ein Unternehmen sich befindet (vgl. Abb. 2). Damit soll nicht gesagt werden, dass traditionelle Werte und Vorgehensweisen ihre Bedeutung verlieren, die Prioritäten verschieben sich jedoch von einem statischen hin zu einem agilen Umgang [Bec00].

3 Die zwölf agilen Prinzipien

Als praktische Anleitung für den Umgang mit Komplexität und Dynamik bieten die zwölf agilen Prinzipien eine Orientierung. Die agilen Prinzipien [Bec00] besagen:

- Die Bedürfnisse von Kunden haben höchste Priorität
- Begrüßung von sich verändernden Anforderungen – sie sind der Wettbewerbsvorteil des Kunden
- Häufige Auslieferung funktionierender Produkte
- „Business people“ und Entwickler arbeiten regelmäßig zusammen
- Motiviere die Mitarbeiter und lasse sie weitgehend selbstständig arbeiten
- Fördere und fordere direkte Kommunikation
- Endlos beständiges Tempo – die ursprünglichen Arbeitszeiten sollen eingehalten werden
- Funktionierendes Produkt als Maßstab
- Nutze Wissen über den neuesten technischen Fortschritt
- Einfachheit – minimiere unnötige Arbeit

- Bilde selbstorganisierte Teams
- Regelmäßige Selbstreflexion.

Diese Prinzipien müssen sich in der Modellierung der Prozesse innerhalb eines Unternehmens abbilden. Wie Prozesse in turbulenten Phasen gestaltet werden können, um diesen Anforderungen gerecht zu werden, wird im Folgenden an zwei Beispielen gezeigt, die traditionelle mit agilen Werten kombinieren und diese Kombination in unterschiedlicher Weise umsetzen.

4 Stage-Gate-Modell und Gegenstromprinzip – agil gelebt!

Das erste Beispiel zur Modellierung von Unternehmensprozessen ist das Stage-Gate-Modell nach Robert Cooper [Coo02] (vgl. Abb. 3). Der Stage-Gate-Prozess unterteilt ein Entwicklungsvorhaben in mehrere, jeweils abgeschlossene Abschnitte durch so genannte Tore (Gates). Die Einteilung in die einzelnen Abschnitte erfolgt dabei sachlogisch, so dass eine Invention zu Beginn des Stage-Gate-Prozesses zunächst im Hinblick auf ihre technische und betriebswirtschaftliche Güte analysiert wird, ehe sie an die Entwicklung übergeben und zur Serienreife und anschließenden Markteinführung gebracht wird. Die Anzahl der Abschnitte variiert in Abhängigkeit von den Bedürfnissen der Branche, der einzelnen Unternehmung sowie des jeweiligen Unternehmens. Die „Gates" sind zwischen den einzelnen Abschnitten positioniert und fungieren als Meilensteine. Bevor ein Projektteam die Aufgaben des nächsten Abschnitts in Angriff nehmen kann, wird im Rahmen der Gates eine Entscheidung getroffen, ob das Projekt fortgeführt oder abgebrochen wird. Dabei wird das Projekt an vorab definierten Resultaten und Kriterien bemessen. Ziele sind hier vor allem die Qualitätsverbesserung des Prozesses, eine schärfere Fokussierung sowie die Möglichkeit, mehrere Prozesse parallel und in hohem Tempo durchführen zu können. Weiterhin sollen bereichsübergreifende Teams eingesetzt werden, d. h. Aufgaben und Entscheidungen werden niemals von einer einzelnen Organisationseinheit, etwa der Forschung oder dem Marketing, alleine getragen, sondern alle partizipierenden Bereiche übernehmen Pflichten und Verantwortung. Weiterhin sind die einzelnen Abschnitte idealtypisch so zu gestalten, dass eine Vielzahl von Aktivitäten von den Mitarbeitern aus den verschiedenen Funktionsbereichen parallel abgearbeitet werden kann. Mittels der fortlaufenden Bewertung, ob ein Projekt fortgeführt oder abgebrochen werden sollte, gelingt es, die Ressourcen einer Unternehmung effektiver auf das Projektportfolio zu verteilen und insgesamt zu optimieren. Dies kann allerdings nur dann gelingen, wenn der Stage-Gate Prozess vollständig, auf die Branche adaptiert eingeführt und konsequent danach gelebt wird [PSW]. Neben den traditionellen Projektmanagement-Methoden werden auch agile Prinzipien umgesetzt. So bieten z. B. die einzelnen Gates die Möglichkeit der mehrmaligen Auslieferung funktionierender (Teil-)Produkte bzw. Teillösungen. Auch dem Prinzip der Zusammenarbeit der Business People mit den Entwicklern wird durch die Einbindung aller Abteilungen genüge getan.

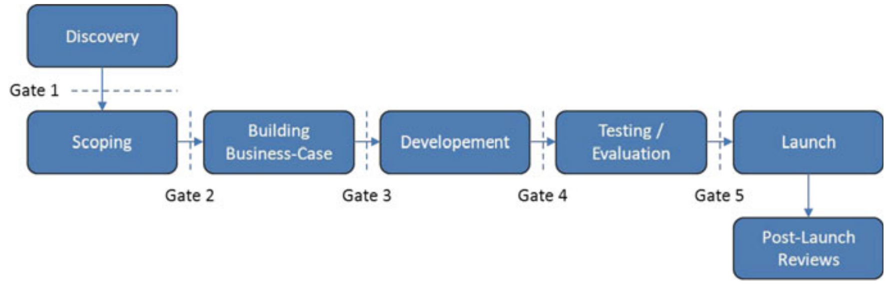

Abb. 3 Beispiel für einen Stage-Gate-Prozess [CE09]

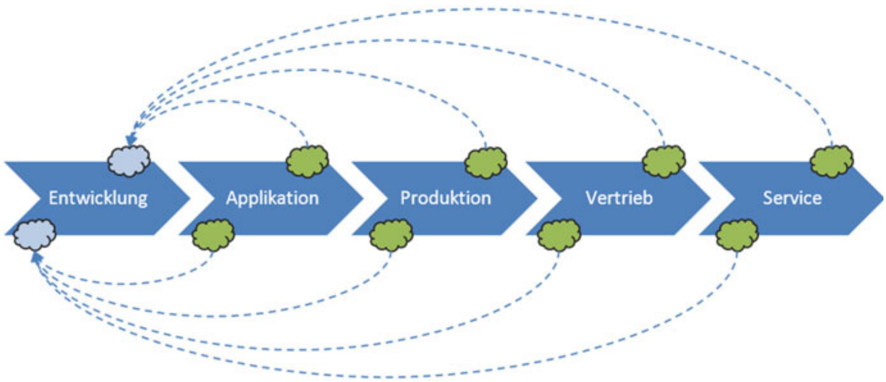

Abb. 4 Gegenstromprinzip

Als zweites Beispiel soll an dieser Stelle das Gegenstromprinzip angesprochen werden [WK03] (vgl. Abb. 4). Das Gegenstromprinzip ist ein Verfahren zur Entwicklung von Unternehmenszielen und zur Planung in Unternehmen. Dabei werden zunächst vorläufige übergeordnete Ziele durch die Führungsebene formuliert. Durch die nachgeordneten Ebenen werden diese Ziele anschließend zerlegt, auf Umsetzbarkeit geprüft und konkretisiert. Mit den daraus resultierenden Verbesserungs- und änderungsvorschlägen gehen diese Informationen als Rückfluss wieder zurück zur Führungsebene, wo der Abgleich und die Koordination dieser Teilziele oder -pläne erfolgt. Dies geschieht allerdings nicht nur auf der Führungsebene, auch zwischen den einzelnen Prozessschritten findet ein regelmäßiger Austausch statt. Das Gegenstromprinzip stellt somit eine zeitlich versetzte Kombination aus Top-down- und Bottom-up-Planung dar und versucht, die Vorteile beider Ansätze zu vereinen.

5 Zusammenfassung

Die Komplexität und Dynamik, denen heutige Unternehmen im globalisierten Markt ausgesetzt sind, lassen sich nicht reduzieren. Dies birgt aber nicht nur die Gefahr, die Kontrolle über das Unternehmen und seinen Output zu verlieren, sondern bietet auch Chancen zur Steigerung der Innovationsfähigkeit des Unternehmens. Daher ist es wichtig, die Prozesse innerhalb eines Unternehmens so zu modellieren, dass das Unternehmen auch in turbulenten Kontexten bestehen kann. Unternehmen und ihre Mitarbeiter müssen dabei unterstützt werden, sich über ihre eigenen Strukturen und Prozesse bewusst zu werden und diese dann agil zu gestalten. Die oben dargelegten Beispiele des Stage-Gate-Modells sowie des Gegenstromprinzips stellen Möglichkeiten dar, Komplexität in verschiedenen Stufen darzustellen und nutzbar zu machen. Letztendlich muss aber jedes Unternehmen für sich definieren, wie es angemessen mit der Komplexität und Dynamik seiner Umwelt umgeht und wie es diese für sich in Innovationskraft umwandeln kann. Um dies zu erleichtern, benötigen Unternehmen Werkzeuge, die es ihnen erlauben, die eigene Situation zu analysieren und Möglichkeiten zu identifizieren, wie bislang noch nicht ausgeschöpfte Potentiale nutzbar gemacht werden können. Der Beitrag von Tummel et al.: „Potenziale smarter Innovation finden“ [THB+12] thematisiert die Entwicklung eines IT-basierten Werkzeugs zur Identifikation verborgener Innovationspotenziale und deren Aktivierung durch gelebte agile Konzepte.

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Wie lässt sich Komplexität als Quelle für Innovationen nutzen?

Ingrid Isenhardt, Max Haberstroh, Marina Scheiff, Christian Tummel, Ralph Kunze, Eckart Hauck

Zusammenfassung Die Komplexität und Dynamik, denen heutige Unternehmen im globalisierten Markt ausgesetzt sind, lassen sich nicht reduzieren. Dies bringt aber nicht nur die Gefahr mit sich, die Kontrolle über das Unternehmen und seinen Output zu verlieren, sondern birgt auch Chancen zur Steigerung der Innovationsfähigkeit des Unternehmens. Daher ist es wichtig die Prozesse innerhalb eines Unternehmens so zu modellieren, dass das Unternehmen auch in turbulenten Kontexten überleben kann. IT-Tools helfen dabei die verschiedenen Dimensionen von Komplexität und Dynamik zu nutzen, indem sie Unternehmen und ihre Mitarbeiter dabei unterstützen sich über ihre eigenen Strukturen und Prozesse bewusst zu werden und diese agil zu gestalten. Die oben dargelegten Beispiele des Produktlebenszyklus, des Stage-Gate-Modells sowie des Gegenstromprinzips stellen eine Möglichkeit dar, Komplexität in verschiedenen Stufen darzustellen und nutzbar zu machen. Letztendlich muss aber jedes Unternehmen für sich herausfinden, wie es mit der Komplexität und Dynamik seiner Umwelt umgeht. Um dies zu erleichtern benötigen Unternehmen Werkzeuge, die es ihnen erlauben, die eigene Situation zu analysieren und Möglichkeiten zu identifizieren, wie bislang noch nicht ausgeschöpfte Potentiale nutzbar gemacht werden können. Ein Werkzeug das für diesen Zweck entwickelt wurde, stellt das IT-Tool „Smarte Innovation" dar.

Schlüsselwörter: Dynaxity, Innovationsfähigkeit von Unternehmen, Smarte Innovation

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1 Einleitung – Komplexität Problem oder Innovationsquelle?

Obwohl längst im Problembewusstsein von Wissenschaftlern und Managern, die sich mit Organisationsentwicklung beschäftigen, ist und bleibt es eine große Herausforderung für Organisationen und ihre Mitglieder, in einem komplexen, vernetzten und dynamischen Umfeld erfolgreich handlungs- und damit überlebensfähig zu bleiben. Die Suche nach Wegen zur Bewältigung von Komplexität hat in verschiedenen wissenschaftlichen Disziplinen zu Ansätzen geführt, die sich mit weitgehend unberechenbaren Wirkungsstrukturen und -prozessen auseinandersetzen (z. B. Feld- und Systemtheorie, Autopoiese- und Chaostheorie, Konstruktivismus). Seit den 90er Jahren bereits versucht man verstärkt diese Erkenntnisse für das Management von Organisationen nutzbar zu machen. Allerdings trifft dies in Produktionsunternehmen auf etablierte Struktur-, Führungs- und Verhaltensmuster, die zumeist unter statischeren Bedingungen entstanden sind. Es entwickelte sich häufig ein „technokratisch-bürokratisches“ Management mit einer horizontal und vertikal ausgeweiteten Arbeitsteilung, „objektivierten“ und präzise vorgeschriebenen Kommunikationswegen und genau definierten Zuständigkeitsinstanzen. Dieses klassische hierarchische Steuerungssystem, bei dem Planbarkeit, Kontrollierbarkeit und Sicherheit oberste Priorität haben, ist immer noch in vielen Unternehmen wirksam während Umgangsstrategien mit Komplexität wie Flexibilität, Improvisationskunst und Selbststeuerung zwar propagiert aber nicht nachhaltig implementiert sind. Im Folgenden wird aufgezeigt wie genau durch solche komplexitätsorientierten Prinzipien Innovationsimpulse – im Sinne von Produkt- und Prozessinnnovation – erfolgreich im Unternehmen gesetzt werden können.

2 Organisationsmethaphern

Bilder im Kopf bestimmen was wir sehen und wie wir handeln: Die dem jeweiligen Unternehmensmodell zugrunde liegenden Metaphern haben einen erheblichen Einfluss auf die Gestaltung der Prozesse und die Art der Zusammenarbeit innerhalb der Unternehmen. Wird ein Unternehmen von Führungskräften und Mitarbeitern wie eine Maschine betrachtet, überwiegen einheitliche Vorschriften. Zentrale Entscheidungen werden als Voraussetzung für Arbeits- und Handlungsfähigkeit gefordert. Es überwiegt der Wunsch nach Spezialisierung der Mitarbeiter und Abteilungen und eine Standardisierung ihrer Arbeit – sicher auch, weil Fehlerzuweisungen und Absicherungsstrategien in diesen Gebilden besser gelingen. Die Aufgaben der einzelnen Abteilungen und Mitarbeiter greifen „wie Zahnräder“ ineinander – Redundanzen und überlappungen sind eher unerwünscht – weil ineffizient. Die Umwelt wird vor allem von Abteilungen und Personen, die nicht im direkten Kundenkontakt stehen häufig als „Störgröße“ betrachtet. Auf diese Weise wird versucht die Komplexität im Unternehmen zu reduzieren und der kreative Umgang mit der Umwelt und ihren Anregungen an die zuständigen Abteilungen – Vertrieb und Marketing delegiert. Dagegen stehen Modelle, die Unternehmen als lebende, dynamische Systeme be-

Abb. 1 Gegenüberstellung traditioneller und agiler Strategien

greifen, welche die Außenkomplexität im Inneren abbilden [Ash63], Austauschprozesse mit ihrer als Innovationsquelle erkennen und kreative Redundanzen nutzen. Im Gegenzug akzeptieren sie eine nur bedingte Steuerbarkeit. Unternehmen, denen ein solches organisches Organisationsverständnis zu Grunde liegt, haben das Potential die Dynamik für sich zu nutzen und so ihre Innovationsfähigkeit zu steigern [Ise94].

3 Nicht „Entweder – Oder" sondern „Sowohl – als auch"

Eine strikte Trennung zwischen starren bzw. mechanistischenschen und dynamischen Systemen ist jedoch nicht zielführend. Regeln, Standards und Tools sind auch für Organisationen in turbulenten Umgebungen für die Strukturierung und das Steuern grundlegender Prozesse sinnvoll. Um mit steigender Komplexität und Dynamik umzugehen sind jedoch ergänzende Strategien notwendig. Die Auswahl situationsangepasster Strategien stellt eine Schlüsselkompetenz für Unternehmen und ihre Mitarbeiter dar, wenn sie in turbulenten Kontexten erfolgreich sein wollen. Dementsprechend geht es darum, traditionelle und agile Werte zu verbinden und damit Raum für Innovationen zu schaffen. Abbildung 1 stellt beispielhaft unternehmerische Strategien vor, die grundsätzlich die beiden vorgestellten Metaphern/Managementperspektiven repräsentieren.

Bei der Gegenüberstellung geht es weniger um ein entweder oder, als um ein sowohl als auch, da beide Ansätze – abhängig vom Kontext – zum Erfolg eines Unternehmens beitragen können. Das Sammeln, Zusammenführen und Aufbereiten quantitativer Daten beispielsweise ist natürlich ein wesentlicher Bestandteil eines erfolgreichen Wissensmanagements. Es kann jedoch nicht die Vernetzung von Mitarbeitern, Kunden und Partnern ersetzen, durch die der Austausch impliziten Wissens gefördert werden kann. Ebenso wenig kann auf die unternehmensweite Einführung neuer Techniken verzichtet werden. Der damit einhergehende kulturelle Wechsel bedarf aber mindestens genauso viel Beachtung. Das Gleiche gilt für Handbücher, Normen und Standards, die einen unumstrittenen Beitrag zur erfolgreichen Steuerung von Unternehmen leisten. Um Platz für Innovationen zu lassen, müssen die Prozesse jedoch agil gestaltet und Wege jenseits der Normen und Standards ermöglicht werden.

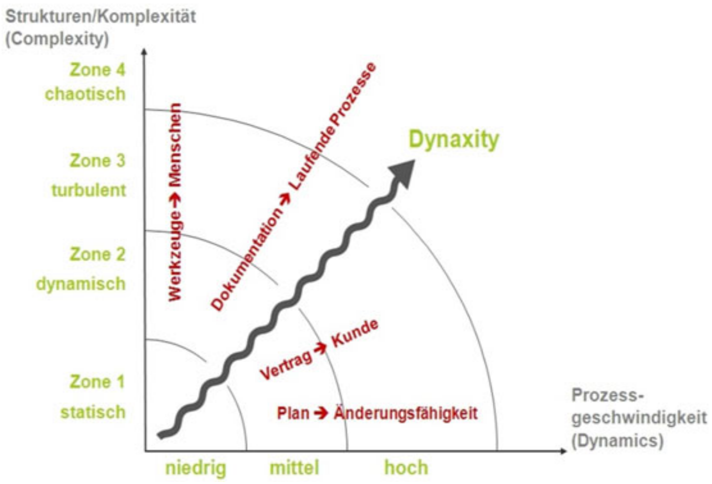

Abb. 2 Die organisationale Umwelt wird zunehmend komplex und dynamisch [Til06]

4 Wie wär's mit: Dynaxity und Agilität?

Mit steigender Komplexität und Dynamik – von Henning mit dem Kunstwort „Dynaxity" [Hen99] bezeichnet – wächst auch die Wichtigkeit der Einbeziehung agiler Werte um ein Unternehmen überhaupt steuern zu können. Dementsprechend gelten die Werte des Agilen Manifests, dass Individuen und Interaktionen wichtiger sind als Prozesse und Werkzeuge, funktionierende Produkte eine höhere Bedeutung haben als umfassende Dokumentation, die Zusammenarbeit mit dem Kunden höher einzuschätzen ist als Vertragsverhandlung und dass die Fähigkeit auf Veränderung zu reagieren wichtiger als das Befolgen eines Plans ist, umso mehr, je dynamischer und komplexer die Umwelt ist in der ein Unternehmen sich befindet (vgl. Abb. 2). Damit soll nicht gesagt werden, dass traditionelle Werte und Vorgehensweisen ihre Bedeutung verlieren, die Prioritäten verschieben sich jedoch von einem statischen, hin zu einem agilen Umgang [Bec].

Als praktische Anleitung für den Umgang mit Komplexität und Dynamik, bieten die zwölf agilen Prinzipien eine Orientierung. Die Agilen Prinzipien besagen [Bec]:

1. Die Bedürfnisse von Kunden haben höchste Priorität
2. Begrüßung von sich verändernden Anforderungen – sie sind der Wettbewerbsvorteil des Kunden
3. Häufige Auslieferung funktionierender Produkte
4. Geschäftsleute und Entwickler arbeiten regelmäßig zusammen
5. Motiviere die Mitarbeiter und lasse sie weitgehend selbstständig arbeiten
6. Fördere und fordere direkte Kommunikation
7. Endlos beständiges Tempo: Die ursprünglichen Arbeitszeiten sollen eingehalten werden.
8. Funktionierendes Produkt als Maßstab

9. Nutze Wissen über den neuesten technischen Fortschritt
10. Einfachheit: Minimiere unnötige Arbeit
11. Bilde selbstorganisierte Teams
12. Regelmäßige Selbstreflexion.

Im Weiteren wird diskutiert, welche Bedeutung die agilen Werte und Prinzipien für die Modellierung der Prozesse innerhalb der Unternehmen haben und in wieweit IT-basierte Tools dazu beitragen können, die verschiedenen Dimensionen der Komplexität zu nutzen.

5 Modellierung von Prozessen in komplexen Umgebungen

5.1 Produktlebenszyklus nach VDMA

Die oben beschriebene Komplexität und Dynamik muss sich auch in der Modellierung der Prozesse innerhalb eines Unternehmens abbilden. Für Unternehmen in turbulenten Phasen bedeutet dies, dass standardisierte Abläufe und klare Abgrenzungen zwischen Prozessschritten nicht ausreichen, um mit Komplexität und Dynamik umzugehen. Wie Prozesse gestaltet werden können um diesen Anforderungen gerecht zu werden, wird im Folgenden an drei Beispielen gezeigt, die Traditionelle mit Agilen Werte kombinieren und diese in unterschiedlicher Weise umsetzen. Das erste Beispiel ist der Produktlebenszyklus des VDMA [lei08] (vgl. Abb. 3), welcher ein umfassendes Konzept zur ganzheitlichen Steuerung und Verwaltung aller produktbezogener und prozessrelevanter Daten über den gesamten Produktlebenszyklus hinweg darstellt. Das Product Lifecycle Management (PLM) integriert sämtliche Informationen, die mit dem Produkt verknüpft sind, vom Rohmaterial über die Geometriedaten bis hin zur Fertigung und Entsorgung. Das PLM soll im Besonderen der Beherrschung der Produkt- und Prozesskomplexität dienen und ein einheitliches Prozessverständnis durch alle Prozessschritte hindurch erzeugen.

Effizienz und Transparenz sollen durch eine eindeutige Rollenverteilung bzw. Produktverantwortung, einen durchgängigen Informationsfluss und eine zentrale Datenhaltung gesteigert werden. Daneben ist aber auch der durchgängige Informationsfluss innerhalb des Unternehmens und mit dem Kunden sowie die Lieferantenintegration über den gesamten Produktlebenszyklus von besonderer Wichtigkeit, so dass neben den traditionellen Werten auch einige zentrale Forderungen des agilen Manifests erfüllt sind.

5.2 Stage-Gate-Modell

Das zweite Beispiel ist das Stage-Gate-Modell nach Robert Cooper (vgl. Abb. 4) [Coo10]. Der Stage-Gate-Prozess unterteilt ein Entwicklungsvorhaben in

Abb. 3 Produktlebenszyklus (VDMA, 2008) [lei08]

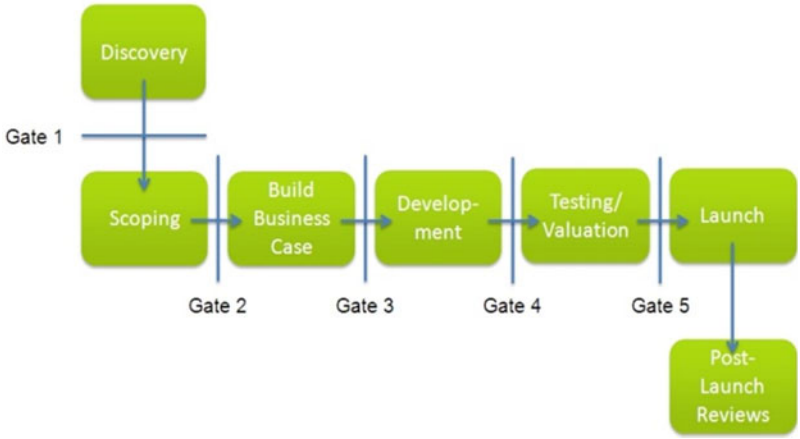

Abb. 4 Beispiel für einen Stage-Gate-Prozess [CE09]

mehrere, alleinstehende Abschnitte durch so genannte Tore (Gates). Die Einteilung in die einzelnen Abschnitte erfolgt dabei sachlogisch, so dass eine Invention zu Beginn des Stage-Gate-Prozesses zunächst im Hinblick auf ihre technische und betriebswirtschaftliche Güte analysiert wird, ehe sie an die Entwicklung übergeben und zur Serienreife und anschließenden Markteinführung gebracht wird.

Die Anzahl der Abschnitte variiert in Abhängigkeit von den Bedürfnissen der Branche, der einzelnen Unternehmung sowie des jeweiligen Unternehmens. Zentraler Bestandteil des Stage-Gate-Modells sind Gates, welche zwischen den einzelnen Abschnitten positioniert sind und als Meilensteine fungieren. Bevor ein Projektteam

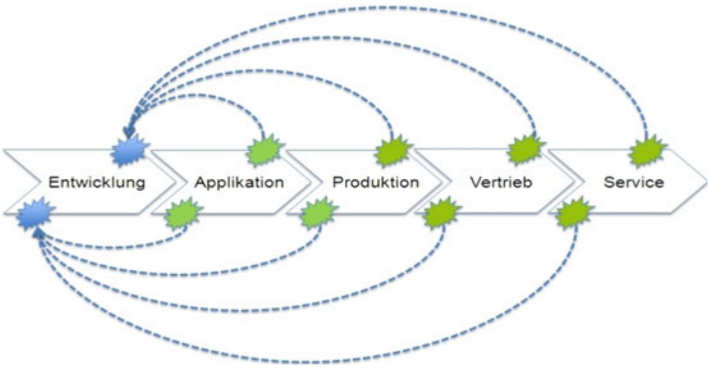

Abb. 5 Gegenstromprinzip

die Aufgaben des nächsten Abschnitts in Angriff nehmen kann, wird im Rahmen der Gates eine Entscheidung getroffen, ob das Projekt fortgeführt oder abgebrochen wird. Dabei wird das Projekt an vorzuweisenden, vorab definierten Resultaten und Kriterien bemessen. Ziele sind hier vor allem die Qualitätsverbesserung des Prozesses, eine schärfere Fokussierung sowie die Möglichkeit mehrere Prozesse parallel und in hohem Tempo durchführen zu können. Weiterhin sollen bereichsübergreifende Teams eingesetzt werden, d. h. Aufgaben und Entscheidungen werden niemals von einer einzelnen Organisationseinheit, wie der Forschung oder dem Marketing, alleine getragen, sondern alle partizipierenden Bereiche übernehmen Pflichten und Verantwortung. Weiterhin sind die einzelnen Abschnitte idealtypisch so zu gestalten, dass eine Vielzahl von Aktivitäten von den Mitarbeitern aus den verschiedenen Funktionsbereichen parallel abgearbeitet werden können. Mittels der fortlaufenden Bewertung, ob ein Projekt fortgeführt oder abgebrochen werden sollte, gelingt es die Ressourcen einer Unternehmung effektiver auf das Projektportfolio zu verteilen und insgesamt zu optimieren [PSW10]. Auch hier werden neben traditionellen Projektmanagement Methoden agile Prinzipien umgesetzt. So bieten z. B. die einzelnen Gates die Möglichkeit der häufigen Auslieferung funktionierender Produkte bzw. Teillösungen. Auch dem Prinzip der Zusammenarbeit von Geschäftsleuten und Entwicklern wird durch die Einbindung aller Abteilungen genüge getan.

5.3 Gegenstromprinzip

Als drittes Beispiel soll an dieser Stelle das Gegenstromprinzip angesprochen werden (Abb. 5) [WK03]. Das Gegenstromprinzip ist ein Verfahren zur Entwicklung von Unternehmenszielen und zur Planung in Unternehmen. Dabei werden zunächst vorläufige übergeordnete Ziele durch die Führungsebene formuliert. Durch die nachgeordneten Ebenen werden diese Ziele anschließend zerlegt, auf Umsetzbarkeit geprüft und konkretisiert.

Mit den daraus resultierenden Verbesserungs- und Änderungsvorschlägen gehen diese Informationen als Rückfluss wieder zurück zur Führungsebene, wo der Abgleich und die Koordination dieser Teilziele oder -pläne erfolgt. Dies geschieht allerdings nicht nur auf der Führungsebene, auch zwischen den einzelnen Prozessschritten findet ein regelmäßiger Austausch statt. Das Gegenstromprinzip stellt somit eine zeitlich versetzte Kombination aus Top-Down- und Bottom-Up-Planung dar und versucht, die Vorteile beider Ansätze zu vereinen.

5.4 Das IT-Tool „Smarte Innovation“

Neben der Modellierung der Prozesse müssen aber auch die eingesetzten Werkzeuge die Dynamik und Komplexität der Umwelt abbilden. Eine Möglichkeit der Abbildung ist das IT-Tool, welches im Projekt „Sinn – Smarte Innovation“ entwickelt wurde. Im Rahmen des Projektes nahmen Projektpartner aus Wirtschaft und Wissenschaft Innovationstreiber und -hemmnisse entlang des gesamten Produktlebenszyklus unter die LupeDas IT-Tool „Smarte Innovation“ orientiert sich daher an den Prozessschritten des Produktlebenszyklus, den im Projekt SInn entwickelten Innovationsdimensionen (Systeme, Menschen, Antizipation, Ressourcen und Technologien) und den 12 Prinzipien des Agilen Manifests. Das Tool ermöglicht auf dieser Basis eine Analyse der Arbeitsrealitäten innerhalb der einzelnen Prozessschritte des PLM auch aus einer Prozessschritt-übergreifenden Sichtweise. Ziel ist die überprüfung, inwieweit diese Arbeitsrealitäten zur Innovationsfähigkeit des Unternehmens beitragen. Die Auswertung der durch das Tool initiierten Mitarbeiterbefragung verdeutlicht, in welchen Prozessschritten möglicherweise ungenutzte Potentiale verborgen sind, die zur Steigerung der Innovationsfähigkeit beitragen können. Durch eine Projektion der identifizierten Innovationstreiber und -hemmnisse an den Agilen Prinzipien, werden abschließend Handlungsempfehlungen angeboten, die zur Aktivierung des identifizierten Potentials und somit zur Steigerung der Innovationsfähigkeit des befragten Unternehmens beitragen können. Aufgegliedert nach den einzelnen Prozessschritten müssen dafür Mitarbeiter eines Unternehmens einen Fragebogen ausfüllen. Mittels einer Fallbeschreibung, die einen beispielhaften Vorgang im jeweiligen Prozessschritt darstellt, soll der Mitarbeiter den Fragebogen sich und seine Arbeitsrealität betreffend ausfüllen. Die hierbei vorgegebenen Fallbeschreibungen adressieren die im Forschungsprojekt SInn identifizierten Treiber- und Hemmnisse für Innovationsfähigkeit in Unternehmen. Zu Innovationstreibern und -hemmnissen gehören beispielsweise die Motivation und Qualifikation der Mitarbeiter, die Kommunikation innerhalb der Abteilungen, Unternehmensabläufe und -prozesse und Abhängigkeiten.

6 Zusammenfassung

Die Komplexität und Dynamik, denen heutige Unternehmen im globalisierten Markt ausgesetzt sind, lassen sich nicht reduzieren. Dies bringt aber nicht nur die Gefahr mit sich, die Kontrolle über das Unternehmen und seinen Output zu verlieren, sondern birgt auch Chancen zur Steigerung der Innovationsfähigkeit des Unternehmens. Daher ist es wichtig die Prozesse innerhalb eines Unternehmens so zu modellieren, dass das Unternehmen auch in turbulenten Kontexten überleben kann. IT-Tools helfen dabei die verschiedenen Dimensionen von Komplexität und Dynamik zu nutzen, indem sie Unternehmen und ihre Mitarbeiter dabei unterstützen sich über ihre eigenen Strukturen und Prozesse bewusst zu werden und diese agil zu gestalten. Die oben dargelegten Beispiele des Produktlebenszyklus, des Stage-Gate-Modells sowie des Gegenstromprinzips stellen eine Möglichkeit dar, Komplexität in verschiedenen Stufen darzustellen und nutzbar zu machen. Letztendlich muss aber jedes Unternehmen für sich herausfinden, wie es mit der Komplexität und Dynamik seiner Umwelt umgeht. Um dies zu erleichtern benötigen Unternehmen Werkzeuge, die es ihnen erlauben, die eigene Situation zu analysieren und Möglichkeiten zu identifizieren, wie bislang noch nicht ausgeschöpfte Potentiale nutzbar gemacht werden können. Ein Werkzeug das für diesen Zweck entwickelt wurde, stellt das IT-Tool „Smarte Innovation“ dar.

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An Efficient Development Process for an Innovative Transport Unit

Sebastian Jursch, Sylwia Jalocha, Eckart Hauck, Sabina Jeschke, Klaus Henning

Abstract The development of a MegaSwapBox (MSB), an innovative transport unit that can transport goods trimodally via rail, road and waterways (short sea and inland shipping), marks an important step towards reducing traffic congestion. The successful development of such an MSB significantly depends on an efficient and economical developing process which allows an effective development from the first idea up to the construction and testing of a prototype. This paper focuses on the development process of such a MSB. It includes methods like an as-is analysis and a requirement specification. An approach for a structured development process, as well as a workshop concept that is used for an effective solution finding are applied. An extended evaluation of the profitability and usability of possible designs leads to the construction of a prototype with the suitable design. This development process will be applied within the TelliBox project "Intelligent MegaSwapBoxes for Advanced Intermodal Freight Transport".

Key words: Development Process, Innovation, TelliBox, Intermodality, MegaSwapBox

1 Introduction

1.1 Initial Situation

Freight transport on road experienced continuous increases for the last decades due to a suboptimal load of rail and inland waterways and short sea compared to the quantity of road transports. This led to an overloading of the road transport system in

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Europe [otEC06]. Since the global market is constantly growing, a further increase can be clearly predicted. In order to relief road, intermodal and resource-saving transport systems need to be supported. Hence, a sustainable intermodal transport system that ensures the transportation of goods via road, rail and waterways (short sea and inland shipping) in one transport unit from sender to recipient as an uninterrupted chain is crucial for European transport policies [Com06].

Currently, many different transport units are used in European freight transport. ISO-Containers, swap-bodies and semitrailers are adapted for certain purposes and markets. But these transport units differ in their dimension and stability as well as their usability regarding handling, transport and loading processes.

Some transport solutions, for example the high-cube containers or jumbo semitrailers, focus on special dimensions, like 45 feet length or 3 m inside height, in order to meet the requirements of most cargos. Others regard the facilities of loading, for example by focusing on curtain-sides or liftable tops. But these single solutions often can only be used in special and separate areas of applications.

As can be seen, intermodal transport lacks an all-purpose transport unit, due to technical constraints particularly with regard to the standardisation of transport units and transshipment technologies. Therefore, the project "TelliBox – Intelligent MegaSwapBoxes for advanced intermodal freight transport" was launched by the European Commission to counteract the trend towards increasing freight transport on roads. The aim was to optimize the concept and design of swap-bodies by combining the advantages of containers and semitrailers for a sustainable intermodal freight transport. Thus, the project focused on the development of a 45 feet all-purpose transport unit, applicable in transport of road, rail, inland and short sea shipping. Additionally, it had to meet special requirements like stackability, applicable for handling from the top, optimised cargo volume of 100 m^3 with an internal height of 3 m and completely openable doors on three sides. At the same time, improved safety features against pilferage had to be ensured [Tel08c].

1.2 Problem Definition

The developing process of such an innovative all-purpose intermodal transport unit that is both cost effective and sustainable requires an appropriate development methodology. This methodology must take into account some elementary aspects which are crucial for a successful and economical product development. [Coo02] First of all, the integration of all relevant stake holders of the intermodal transport chain with all of their challenging and urgent demands has to be ensured. Also, the quality and the costs of the product development have to be taken into account. Additionally, to develop the product economically, it has to be designed with minimal expense and in the shortest time possible. Furthermore, the product needs to meet the consumer's desires and has to be of high quality to reduce expensive repairs and expenditure of time.

This paper focuses on a development process according to VDI 2221 [VDI93] that applies a methodology which pays attention to all of the above mentioned requirements for an effective product development. This methodology combines different analysis and design approaches. Aiming for gathering general ideas and requirements, an as-is analysis and a requirement analysis takes place. Common design approaches, like described in Pahl & Beitz [PBJG07], as well as a "decision on design" workshop are applied for an effective solution finding. The evaluation of the best possible design is done by a profitability and usability analysis and leads to the construction of an optimised prototype (Sect. 2).

Finally, this development methodology will be applied on the European research project TelliBox "Intelligent MegaSwapBoxes for Advanced Intermodal Freight Transport" to demonstrate a successful realised developing process (Sect. 3). The theoretical procedure of this methodology is further specified and applied below.

2 Methodology for the Development of an Innovative Transport Unit

The development process is based on a special approach that is subdivided into the six following phases (see Fig. 1) [JRJH10]: 1) The Analysis phase, 2) the Design & Decision phase, 3) the Elaboration phase, 4) the Evaluation phase, 5) the Construction phase, and 6) the Demonstration phase.

1. *Analysis phase:* An extensive analysis of existing product facilities is essential for the development process of a new product and serves for specification of requirements. This includes the analysis and prioritization of all technical, operational and constructive requirements of the new transport unit by means of interviews, questionnaires and workshops with all parties concerned. Investigations and creative techniques like brainstorming [PBJG07] are used to access the know-how and creativity of each person involved. An additional SWOT analysis [Cla89] helps to discover the strength and weaknesses, opportunities and threats of a new MegaSwapBox. In the next step, all the single solution possibilities are collected with the help of a morphological box [SH07] to establish the solution space representing possible design combinations.
2. *Design & Decision phase:* The objective of this phase is to design possible variants from the solution space and to further develop them considering economical, technical and operational aspects. To create these variants a "Decision on Design"-Workshop is implemented which includes among others an innovative and effectiv method for creative solution finding, named "speed dating" [JRJH10]. Additionally, other methods like the morphological analysis [Zwi69] and so on are used. To analyse the feasibility of each concept, proven scientific methods, for example the "Finite element method" (FEM), are used [Bra02].

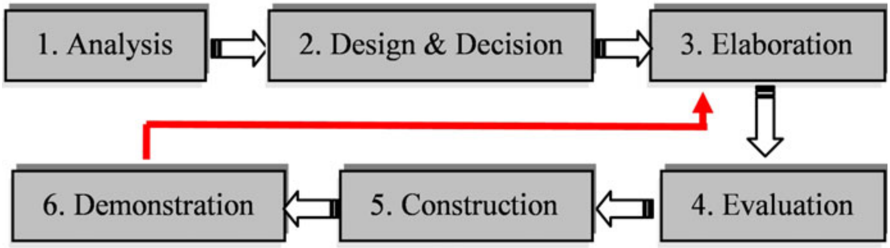

Fig. 1 Approach for the development of an innovative transport unit

3. *Elaboration phase:* In the third phase the elaboration of the chosen variants of the transport unit take place by optimising and designing the single components of the variants with the help of finite element methods (FEM).
4. *Evaluation phase:* Before constructing a prototype, the usability and profitability of the solutions regarding their application on rail, short sea and inland shipping and road must be evaluated. Therefore, different calculations of economic efficiency are carried out using traditional static profitability analysis, such as Return on Investment (ROI) and traditional dynamic profitability methods like the Net Present Value (NPV) [Hir08, Kru04]. Furthermore, the Value oriented cost-effectiveness estimation (NOWS) [Wey00] is applied to determine the economic feasibility of each of the possible solutions. Additionally, a usability analysis is conducted by means of interviews with all parties (e. g., customers) involved along the transport chain. Afterwards, the results are summarised and the usability of all concepts evaluated. After the identification of the most economically, operationally and technically suitable design the prototype is set up.
5. *Construction phase:* Here, the individual components are manufactured and finally assembled to a 1 : 1 prototype. Then, the prototype is tested and certified as eligible e. g. by CSC and UIC to be used in the transport system.
6. *Demonstration phase:* The realised prototype is tested under real conditions for all transportation modes (road, rail, short sea and inland shipping), as well as for the handling processes in terminals. In addition, tests concerning the loading and unloading of freight are carried out. Through this test phase, an evaluation of the quality of the prototype that considers both technical and operational aspects is done. According to the iterative approach of VDI 2221 [VDI93] and based on this evaluation, an improvement of the prototype can take place. Therefore, an optimization loop is integrated within this phase which leads back to the third phase, so that there the transport unit can be redesigned or just a modification of individual components can be applied. After reengineering, the prototype is tested and evaluated like beforehand.

The involvement of all partners, from the first idea to the final construction of the prototype, is essential for the whole development process and a major element of this approach.

3 Application of the Design Process

Since the aim of the "TelliBox" project is to generate an applicable, custom-oriented and technical feasible intermodal transport solution by encouraging dialogue between industrial and scientific partners, an interdisciplinary European consortium was involved in the development process. The consortium consisted of operators, logistic enterprises, manufacturers and research institutes. They took part in the whole developing process from the very beginning till the construction of the prototype, applying the above presented approach as follows:

3.1 Analysis Phase

The Analysis phase is subdivided into four items: the As-is analysis, the requirement specification, the analysis of the developed solutions, the solution space. There are several intermodal systems in the transport market, like containers (ISO and High-Cube (HC)), swap bodies, semi-trailers, and so on. Each of them is used in different ways related to its design, technology, transportation (road, rail, inland waterways or short sea) and handling. And each has its advantages and disadvantages. To figure out, whether a new intermodal transport unit like the proposed MSB is demanded on the European transport market, the consortium had to identify the strengths and weaknesses of each intermodal transport unit existing on the market and compare them to the MSB. This happened by means of an As-is analysis using the consortiums knowledge, literature research as well as questionnaire distributed to the major European transport forwarders and manufacturers. One result was a comparison matrix in which the advantages and disadvantages of the individual intermodal transport units were presented and compared to the MSB (see Table 1) [Tel08a].

Furthermore, an analysis of the individual intermodal transport units utilised in the trimodal transport took place. The conclusion was that there is a need for a new high capacity MSB that could satisfy conditions of trimodal usage and having a design that enables loading from the rear and sides. Additionally, the applied SWOT analysis identified strengths (like stackability, etc.), weaknesses (e. g., building a customer's base), opportunities (e. g., new export markets) and threats (insufficient transport infrastructure, etc.) of the assumed MegaSwapBox. These results, specially the questionnaires, were used for a requirement specification. Therefore, a dedicated workshop of the consortium members took place. The participants were divided into three groups (road, rail and shipping) and during a brainstorming the ideas were written and summarised on boards. Requirements that had been worked

Table 1 Comparison matrix

	Container ISO 1A	Container HC 45'	Swap body (series A)	Semitrailer (Jumbo)
Trimodal	+	+	–	–
Stackable	+	+	0	–
Handling from top	+	+	–	–
Cargo vol. 100m³	–	–	+	+
3m internal height	–	–	+	+
Loading facilities from three sides	0	0	0	+
Safety of cargo (pilferage / theft)	+	+	0	0
Liftable top	0	0	0	+

Legend: + standard, 0 purpose-built, – none

out were for example stackability, applicable for handling from the top, optimised cargo volume of 100 m^3 with an internal height of 3 m and three sides, which implies completely openable doors, and so on. The final result of this phase was the development of a solution space for the design of the MSB by analysing various solution possibilities. Therefore any ideas for the realisation of the single components regarding technologies, designs and materials based on new ideas as well as existing solutions were collected and discussed regarding their advantages and disadvantages. Within the morphological box possible characteristics with their values for the MSB were listed based on the discussed materials (see Fig. 2). Each specific combination of the values was guided by a certain criterion, like costs, weight, and so on. The solution space represented possible combinations of these solutions and served as a frame when deciding how to design the MSB.

3.2 Design & Decision Phase

Having determined the solution space, the task within the second phase was to reduce and combine all the solutions to three possible designs. A workshop concept, called "Decision on Designs Workshop" [JRJH10], was applied in the design stage of solution development. The workshop focused on the encouragement of all participants in the whole solution-development-process and gave them the possibility to contribute their own ideas and to discuss them without prejudice [LeM01, Ung98]. Within the workshop a novel method named "speed dating" was applied. The aim was to get acquainted with all of the design concepts. The original speed dating strategy was invented for busy professionals to optimize the time they spend while

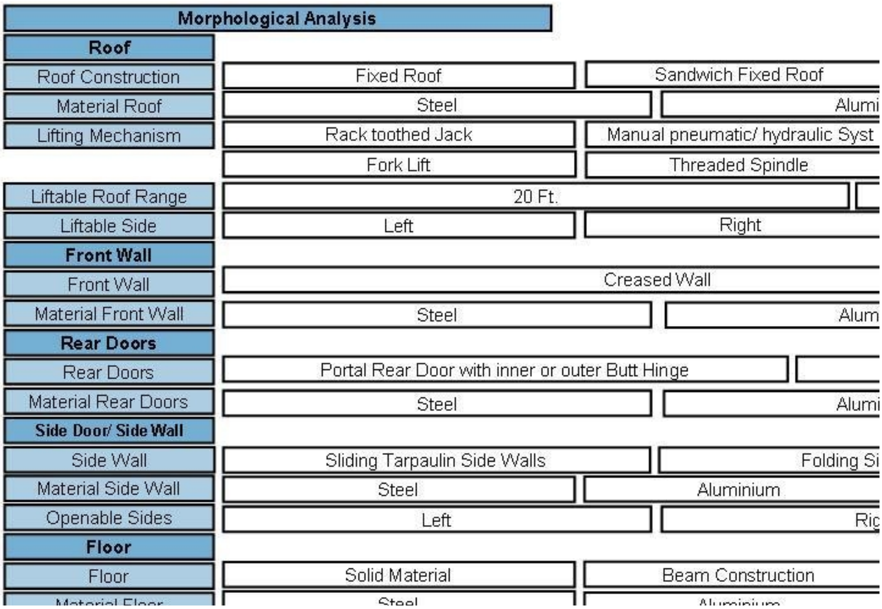

Fig. 2 Morphological box [Tel08a]

dating. Here, it was modified for the industry to offer a more efficient way to share knowledge and find solutions. A common approach and understanding was ensured through evaluation criteria and their description. Each participant was alternating between presenting his idea of a possible design to the partner and to listen to the presentation of the partner's design. Feedback was given continuously. By means of an improvement and documentation loop, the participants had the chance to improve and document their designs. The speed dating part itself was followed by group work aiming to put all idea and solution proposals of this working session into a morphological box. After discussing the filled morphological boxes of every group, feedback was given and the ideas improved until there were three solutions [JRJH10]. To support this process, the morphological analysis was employed in the workshop. This creativity technique made it possible to combine the features of a design and produce particular solutions. Additionally, a feasibility study took place in order to identify the possibilities to construct a new 45 feet MSB which has an inside height of 3 m, is stackable and has three openable sides [Tel08b]. To analyse possible MSB constructions, different 3D models were developed. These models helped to study statically the calculations of deflection, tensions and reaction forces which occur when the MSB is loaded. The method used for the feasibility study was the FEM method, which is a powerful technique developed for numerical solutions of complex problems. It is used to carry out a large variety of static and dynamic analyses for dimensioning and verification purposes. Using the workshop concept and the feasibility study, the participants of the interdisciplinary consortium were able to work out three solutions for a new intermodal transport unit that appeared to be the most suitable (technically and operationally) for the transport system and that were accepted by all stakeholders.

a) The Fala-EC-Box design: The main idea is to have one fixed side wall on the right side and folded side walls on the left side. On the left side of the bottom frame the height of outside frame is reduced to the middle. The roof is liftable in the middle area (between the 40 feet corner castings) with mechanical system (toothed rack). The rear portal door is a two in one door construction. That means that a small door is integrated in the big rear portal door to reduce the opening range in terminals.
b) The AirTech-Box design: The main idea of the AirTech solution is to have a fixed bottom frame, a liftable floor and fixed sidewalls (1/5 of the overall height). The liftable bottom frame is used as the loading platform which is lifted by using airbags and external energy.
c) The Shoe-Box design: The main idea of the Shoe-Box design is based on a shoe box. A closed shoe box is stable, but if one removes one or more sides of the shoe box, it becomes less stable. Using this construction principle, the Shoe-Box can be stabilized if the side doors are part of the body construction. It was possible to transfer the shoe box concept on this solution with openable doors. The roof of the Shoe-Box solution is liftable and openable over the whole range of the transport unit with mechanical system (toothed rack).

3.3 Elaboration Phase

The third phase comprised the detailed elaboration of the three chosen variants of the MSB. To evaluate the concepts, calculations and simulations of the static and the driving dynamic characteristics were executed. Furthermore, simulation tools like the 'finite element method' were used.

3.4 Evaluation Phase

Before an optimal solution was chosen, the three designs were evaluated regarding criteria like profitability and usability. To estimate the profitability of each of the three designs, the Return of Investment (ROI) and Net Present Value (NPV) were determined. Additionally a NOWS workshop took place to estimate the value orientated cost-effectiveness. The NOWS method [Wey00, SU04, SUH03] was developed by the Institute for Management Cybernetics at RWTH Aachen University and combines the classical analysis of investement in monetary terms with relevant non-monetary variables or the so-called soft factors (e. g., flexibility, costs for employee's training or loss of working hours) in the profitability analysis [Hir08, Kru04]. Each design was assessed independently by a group of the participants of the workshop. The benefits as well as the costs were summarized in

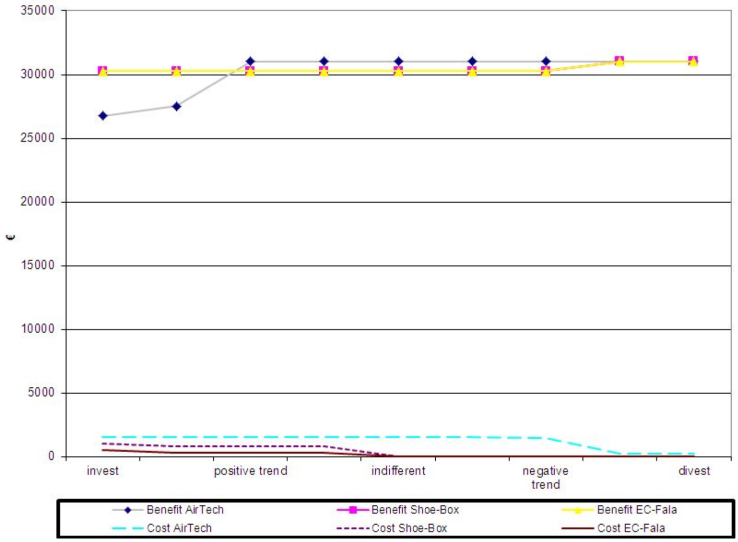

Fig. 3 NOWS-graph [Tel10]

a 3 × 3-matrix containing the occurrence probability and the ascertainability. In order to guarantee a comparability of the results, the groups could discuss their results within a set-up marketplace-phase with the other groups. Of three matrices (one for each solution) all aspects were quantified by all participants together and a NOWS-graph was created (see Fig. 3). After evaluating the results of the NOWS-method and the ROI & NPV, it was stated that an investment for any of the three designs can be recommended. The difference of profitability between the solutions was insignificant. Therefore, a decision on one of the presented designs could not be based on the calculated profitability alone.

Since no clear decision could have been made, an usability analysis was applied. The aim was to investigate the usability of the MSB on rail, short sea and inland shipping and road, including handling at the terminal, based on the given requirements. To this end, interviews were conducted with various parties involved along the transport chain. Different workshops within the consortium and discussions with different stakeholders followed and the consortium jointly decided to concentrate their activities on the so-called Shoe-Box (see Fig. 4).

3.5 Construction Phase and Demonstration Phase

Afterwards, the chosen design was constructed and tested on a testing track as already indicated in Sect. 2. The results of the testing can be used to improve the design.

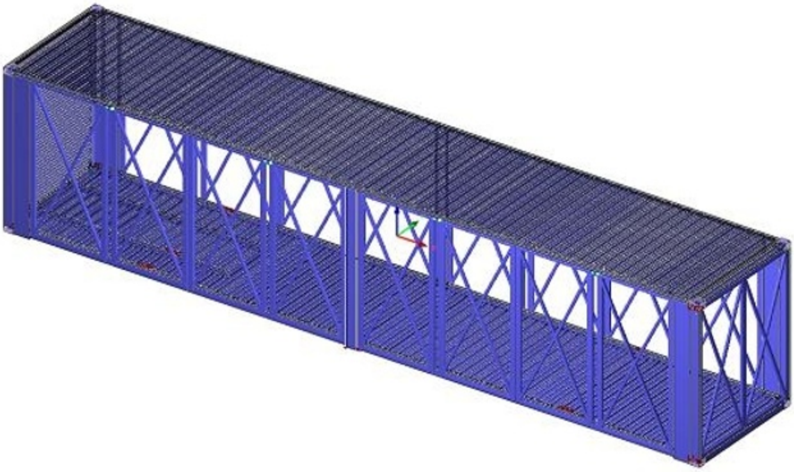

Fig. 4 Shoe-Box design

4 Conclusion and Outlook

The successful development of an MSB requires an efficient and economical development process. As could be shown, the applied development methodology according to [VDI93] represents such an effective approach. Due to this methodology, the MSB was designed with minimal expense and in short time, regarding all the requirements needed. Crucial for this methodology was the steady involvement of all the participants along the transportation chain by the use of questionnaire, interviews and workshops. Furthermore, an agile moderation throughout all workshops was necessary for a smooth implementation. Finally, it was important for every workshop member to be prepared before the beginning of the workshop, as well as to define detailed goals. This methodology seems to be transferrable to other technical product development processes with innovation potential, regarding the following modifications: The As-is Analysis needs to be adapted to the new application case, as well as the cost accounts, profitability and feasibility analysis. Furthermore, it should be analysed, whether this methodology is transferrable to sectors like software-engineering etc.

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Economic Evaluation of "Intelligent MegaSwapBoxes" for Advanced Intermodal Freight Transport Through Value Orientated Cost-Effectiveness Estimation

Sebastian Jursch, Sabine Bischoff, Eckart Hauck, Paul Flachskampf, Sabina Jeschke, Klaus Henning

Abstract The success of intermodal transport solutions compared to exclusive road transport significantly depends on the cost efficiency, the improvement of interoperability and the exploitation of a maximized cargo area. Intermodal transport provides the opportunity to benefit from the advantages of each of the individual transport modes integrated in a system that is both cost effective and sustainable. The development of intelligent MegaSwapBoxes, a seamless and customer-oriented transport concept, marks an important step towards enhancing competitiveness. The paper focuses on the method of the Value Oriented Cost-Effectiveness Estimation. This method had been developed by the Institute for Management Cybernetics at RWTH Aachen University and combines the classical analysis of investment in monetary terms with relevant non-monetary variables or the so-called soft factors in the profitability analysis. In this paper, a new approach of the Value Oriented Cost-Effectiveness Estimation is presented and applied in excerpts within the TelliBox project "Intelligent MegaSwapBoxes for Advanced Intermodal Freight Transport".

Key words: Value Oriented Cost-Effectiveness Estimation, TelliBox, Intermodality, Transport, MegaSwapBox

1 Introduction

1.1 Initial Situation

In the last decades, intermodal freight transport was driven by the changing requirements of global supply chains. The improved integration and compatibility

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between modes provided the necessary scope for a sustainable transport system and the promotion of intermodality offered the opportunity to improve rail, inland waterways and short sea shipping. Presently, these options are seldom used, because they do not allow door-to-door delivery. In the future, the operation grade of carriers will increase significantly and the European Commission prognoses a sub-optimal load of rail and waterways compared to the immoderate quantity of road transports [Com06].

The European road transport system is almost overloaded and currently does not offer enough potential for technological enhancement to face the future increase in traffic [otEC06]. Hence, balancing the modes of transport i. e. intermodal transport is crucial for European transport policies. Today's transport system has to face various challenges in terms of safety, reducing traffic congestion and the improvement of loading processes and interoperability of available transport modes. For a competitive intermodality, the quality and flexibility of interfaces between modes and national transport chains needs to be increased. Additionally, transport costs may be reduced by pursuing the trend towards high-volume loading units. Concerning the dimensions of the loading units, some transport modes may not meet the requirements of every cargo. The lack of standardization of intermodal loading units inhibits the connectivity of modes and generates costs e. g. through the requirement of special transshipment technologies.

Especially developed transport solutions, like the high-cube containers, jumbo semitrailers, curtain-side swap-bodies or boxes with liftable tops, were introduced to the market. However, those specialized solutions often can only be used for some applications and require special operational technologies so that extra costs arise.

The cost efficient use of intermodal transport units depends on several factors like time for loading and unloading, range of interoperability, theft protection, cargo area, loading height etc.

Despite the positive development of the modal split, intermodal transport is hampered by technical constraints particularly when it comes to the standardization of the loading units and transshipment technologies. Therefore intermodal transport lacks all-purpose products.

The project "TelliBox – Intelligent MegaSwapBoxes for advanced intermodal freight transport" has been launched by the European Commission due to the increasing demands from politics and society to counteract the trend towards increasing freight transport on roads. It focused on the development of an all-purpose loading unit, applicable in intermodal transport of road, rail, inland and short sea shipping for the use in Europe and Russia. The aim is to optimize the concept and design of swap-bodies by combining the advantages of containers and semitrailers for a sustainable intermodal freight transport. The objectives of this project are based on the experience of logistic companies, who have been operating in intermodal freight transport for years.

Such a transport unit needs to face several requirements [Tel08] regarding its design and functionality (Fig. 1). It has to be trimodal, be stackable and applicable for handling from the top, use existing low floor wagons for rail transport, have an optimized cargo volume of 100 m^3 with an internal height of 3 m and length of

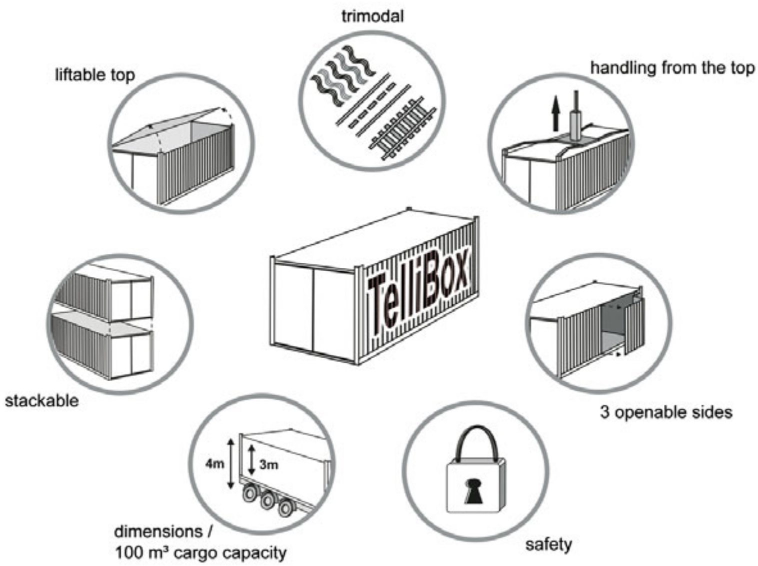

Fig. 1 Requirements the MegaSwapBox has to fulfill

45 feet, have loading facilities from three sides (completely openable doors), offer improved safety features against pilferage.

1.2 Problem Definition

For the evaluation of the designed MegaSwapBoxes, a bundle of influencing criteria, effects and interactions have to be taken into consideration. Hence, for the analysis and evaluation of the profitability of MegaSwapBoxes a holistic approach must be applied, which takes any effect into account. Traditional profitability analysis can not – or just with great difficulty – include these influences and consequences into their approaches. The Value Oriented Cost-Effectiveness Estimation was developed in 2000 by Weydandt [Wey00] to combine the classical analysis of investment in monetary terms with relevant non-monetary variables. With NOWS, the direct cost and benefit factors of several investment of specific scenarios or objects of investigation can be measured. For three designed MegaSwapBoxes (MSB), a potential market launch of one could only be successful, if the benefits of all effects are bigger than their costs. Therefore, within the project TelliBox, three different designs have been developed. These will be evaluated by the later introduced method in terms of their profitability to be able to choose the most economic one. The view on these solutions contains the profitability of freight forwarding companies that use the MSB for their transports. This view focuses on the profitability of the new transport unit on a microeconomic level. The key emphasis here is whether or not the MSB would be profitable for a freight forwarding company. Therefore this paper focuses on the described perspective in order to answer that question. Hence, within the next chapter the three designs respectively scenarios of "Intelligent MegaSwapBoxes for Advanced Intermodal Freight Transport" are described. The Value Oriented Cost-Effectiveness Estimation will be introduced afterwards.

2 Intelligent MegaSwapBoxes for Advanced Intermodal Freight Transport

2.1 Designs for the MegaSwapBox

The project TelliBox has to look for new design concepts for the MSB to fulfill the above stated requirements. Different design workshops were held to discuss and find new designs. In these workshops the solution proposals "AirTech-Box", "Fala-EC-Box" and "Shoe-Box" were designed.

2.2 The AirTech-Box Design

The main idea of the AirTech solution is to have a fixed bottom frame, a liftable floor and fixed sidewalls (1/5 of the overall height). The liftable bottom frame is used as the loading platform which is lifted by using airbags and external energy. The fixed side wall enables the user to have the maximum deflections allowed. Principle behind the fixed side wall is a strongbox. The AirTech system works in addition with folded aluminium side doors on the left and right sides, rear portal doors and steel corrugated front walls, a liftable roof over the whole range with mechanical system and a movable cross member at the rear portal (Fig. 2).

2.3 The Fala-EC-Box Design

The main idea is to have one fixed side wall on the right side and folded side walls on the left side. The bottom frame consists of square elements that are asymmetric constructed. The cross members are not parallel mounted. On the left side of the bottom frame the height of outside frame is reduced to the middle. When loading, the design of the outside frame helps to keep the allowed maximum deflections. The roof can be lifted in the middle area with mechanical system. The rear portal door is a two in one door construction (Fig. 3).

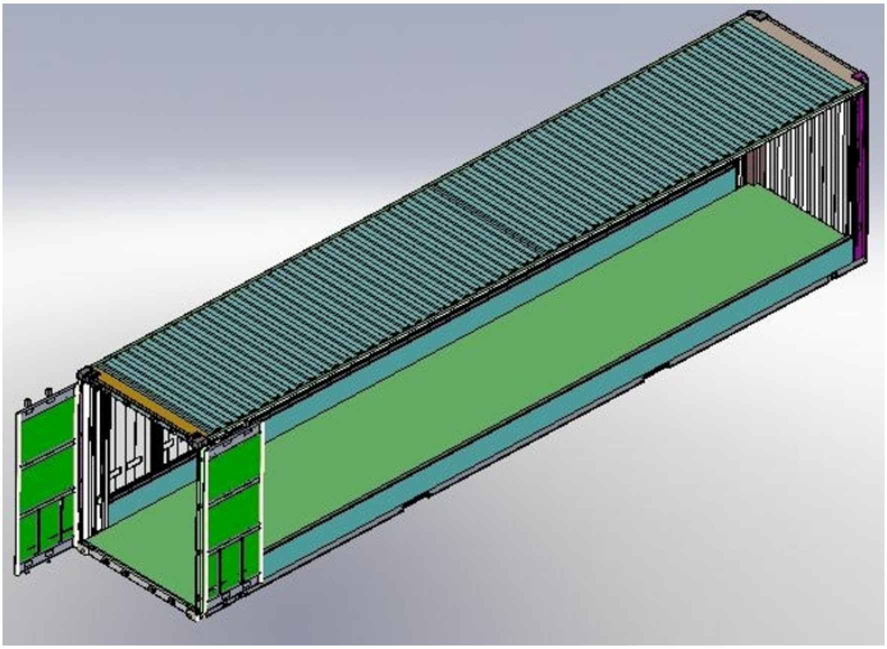

Fig. 2 AirTech-Box solution

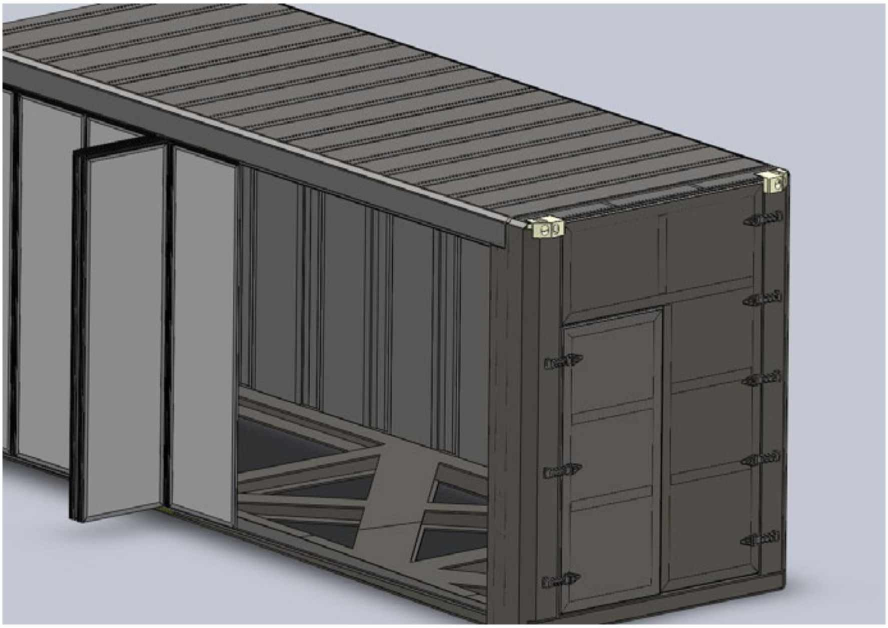

Fig. 3 Fala-EC-Box solution

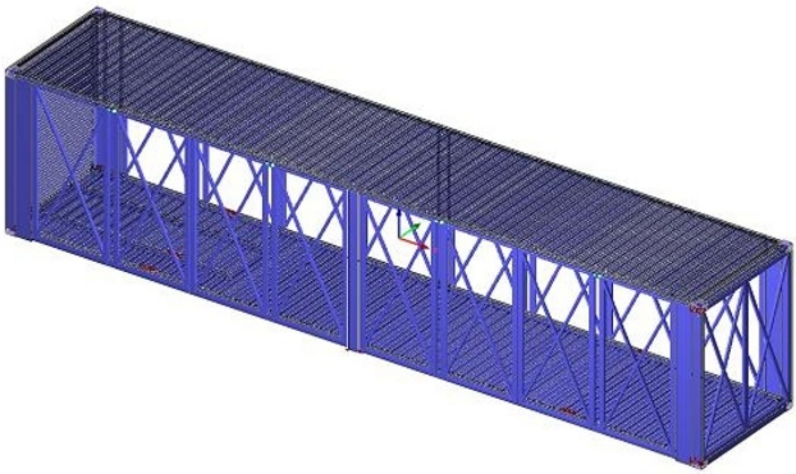

Fig. 4 Shoe-Box solution

2.4 The Shoe-Box Design

The main idea of the Shoe-Box solution is based on a shoe box. A closed shoe box is stable, but if one removes one or more sides of the shoe box, it becomes less stable. Using this construction principle, the Shoe-Box could be stabilized if the side doors are part of the body construction (Fig. 4). It is therefore important for this construction to design the door hinges and door closing elements in such a way that they can take part of the forces which react on the Shoe-Box when being handled. The side door design itself is based on a framework. The roof of the Shoe-Box solution can be lifted and opened over the whole range of the transport unit with mechanical system.

3 Introduction to the Value Oriented Cost-Effectiveness Estimation

It is always difficult to ascertain the benefits and costs of new innovative technologies. However, the economic evaluation of the respective costs and benefits is especially important during the planning and development process.

The method of the Value Oriented Cost-Effectiveness Estimation, also named as NOWS method [SU04, Wey00, SUH03, UHS04], developed by Weydandt in 2000 [Wey00], is a participation-oriented, entrepreneurial cybernetic approach for the evaluation of costs and benefits of an investment. The NOWS method is a participation-oriented, entrepreneurial cybernetic approach for the evaluation of costs and benefits of an investment. The method enables a decision maker on investment opportunities to combine the classical analysis of investment in monetary terms with relevant non-monetary variables or the so-called soft factors in the profitability analysis. The method consists of a monetary examination and an integrated examination of the costs and benefits and it takes into consideration the currently on the market available products. The NOWS method combines the classical analysis of investment in monetary terms with relevant non-monetary variables or the so-called soft factors in the profitability analysis. This approach needs to be considered in comparison to the classical economic efficiency approaches: these conventional approaches limit themselves basically to the quantifiable objectives in terms of monetary data, e. g. costs and revenues (so called "hard" factors). In contrast, the NOWS approach considers non-monetary objectives such as time, quality, flexibility, employee perspectives or enterprise environment to be evaluated in terms of money. Therefore, with NOWS, the different factors for evaluation are distinguished as "direct, indirect and difficult to ascertain". The probabilities of occurrence of certain corresponding events are classified as "high, medium or low". Finally, the NOWS chart shows the monetized cost and benefit curves providing a profitability indicator for the investment. Therefore, this approach supplies the answer to the enterprise requirements which are partly taken from the guidelines for ISO-Certification 9000/2000.

The NOWS method consists of seven phases:

- Constitution of the Interdisciplinary Investment Team,
- Current-Situation-Analysis
- Target-Situation-Analysis
- Compilation of Measures
- Investment calculation and evaluation
- Implementation
- Reflection.

They form the basis for all participation-oriented processes as well as the learning processes [Ung98] of all participants and also the organization (Fig. 5). In the phase "Constitution of the Interdisciplinary Investment Team", a representative team is formed from executives and employees who are affected by the measures and strategies. This team conducts the whole evaluation, implementation and reflection process. During the phase "Current-Situation-Analysis", the existing skills and competencies in the enterprise are identified; in the "Target-Situation-Analysis" phase, the necessary competencies are derived from the strategic objectives, and are identified and classified according to the necessity of reaching them. Phase 4 "Compilation of Measures" defines individual strategies, which are then tested for their economic efficiency in the "Investment calculation and evaluation" phase. This is the core phase of the NOWS method. Within this phase, the costs and benefits of the investment are defined and assigned if they are direct, indirect or difficult to ascertain. They are also assigned regarding their probabilities of occurrence (high, medium or low). The evaluation is concluded by the decision to implement one or several strategies. The benefits as well as the costs get summarized in a 3×3-

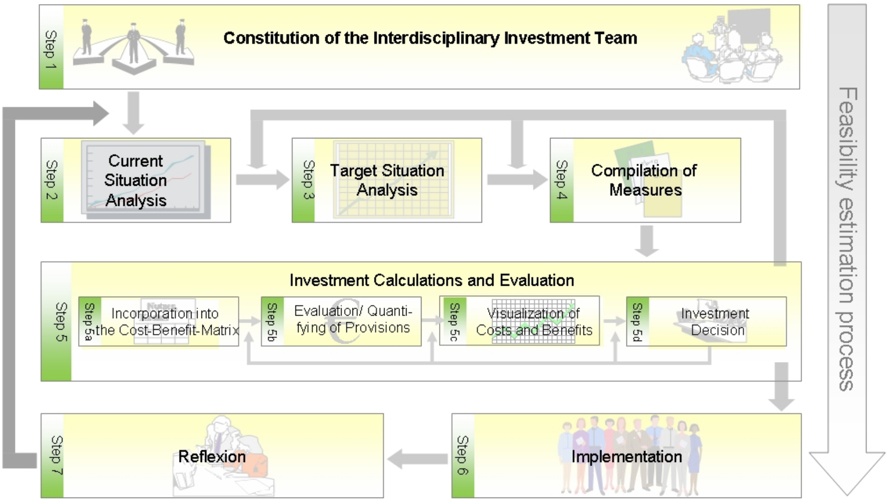

Fig. 5 Value Oriented Cost-Effectiveness Estimation, the NOWS Method [UHS04]

matrix containing the occurrence probability and the ascertainability. Afterwards costs and benefits are monetized and accumulated from direct ascertainability and high probability of occurrence to difficult ascertainability and low probability of occurrence. Afterwards the accumulated costs and benefits get displayed in a NOWS chart. The intersection point of the cost graph and the benefit graph shows if the investment should be accomplished or refused. It is recommended in the "Implementation" phase, that participants from the Interdisciplinary Investment Team directly accompany the process, so that the advice for the evaluation of strategies is directly incorporated into the transfer process. In the "Reflection" phase, the Interdisciplinary Investment Team appraises the experiences gathered during the process (planning, evaluation, implementation and supervision), and it issues recommendations on possible actions for the next implementations, or for the realization of subsequent training and further education processes.

4 Application of the Value Oriented Cost-Effectiveness Estimation on Intelligent MegaSwapBoxes for Advanced Intermodal Freight Transport

4.1 Framework

The Current-Situation-Analysis shows that the openings of boarders in the East of the European Union result in an increase of freight transport volume. The European Union's objectives of achieving intermodal integration and operational optimization can therefore be regarded as the definition of the “Target-Situation-Analysis” (phase three). Intelligent MSBs for Advanced Intermodal Freight Transport can be seen as one possible action to achieve this target situation by shifting the intermodal traffic in favor of rail and short sea traffic (phase four “Compilation of Measures”).

The estimation of the costs and benefits had to be done by an Interdisciplinary Investment Team for three different MSB designs. It was agreed by the consortia of the project that for each design all annually costs and benefits for a freight forwarder operating with one kind of the MSB design had to be evaluated in 2015. At this time it was assumed that the ramp-up phase would have been completed. To achieve an independency, the Investment calculation and evaluation are carried out relatively to standardized swap-bodies which are used today. All benefits respectively costs were classified in their type as well as their probability of occurrence.

Each design of the MSB was assessed independently by a group of the participants. Each group consisted of designated experts. In order to guarantee a comparability of the results, the groups could discuss their results within a set-up marketplace-phase with the other groups. On the basis of the three matrices all aspects were quantified by all participants together.

4.2 Measures

In the following, the derivation of several selected benefit and cost aspects is described. As a main direct benefit with high occurrence, a reduction of transport costs was identified. Referring to a test track, it was agreed that an intermodal transport with the MSB has an advantage, when compared with a swap-body of 0.37 €/km regardless the design of the MSB. Consequently, when the test track accounts one way with 1300 km and 20 cycles/MSB and year are assumed, a benefit of 19,240 € occurs.

Another benefit which can be stated independent of the design is the volume of 100 m^3 of the MSB. Compared to a swap-body with a transport volume of only 80 m^3, this is a gain of 20 %. This increase in volume results in a decrease of necessary traffic and therefore transport costs.

The participants assumed a yearly kilometrage of about 52,000 km for a swap-body. The variable operating costs for the swap-body were assessed as 1.00 €/km. Furthermore it was not regarded as realistic that the freight forwarder can keep this benefit himself but has to pass on one third to his customers. This results in an overall benefit due to an increase in volume of 6968 € per year for every MSB used. Two further common identified advantages of the MSB are its stackability and the ability for transsiberian transport. The MSBs can be stapled fourfold in contrast to the swap-body which is not stackable at all. Therefore four MSBs can be stored on one slot whereas every swap-body needs a separate slot. The fees for one slot account to 10 €/day, resulting in a benefit of 7.50 €/day for the MSB compared to the swap-body. It was assumed that a transport unit is stored on average 37 days per year, being approximately 10 % per year. This leads to a benefit of 277.50 €.

The MSB can be transported to Asia via train with fewer thieveries than today. This comes along with a saving of ten days per cycle for the transport when compared to the longer ocean route. Assuming eight cycles per year, capital costs of 80 days can be saved. Given an interest rate of 6 %, this benefit therefore adds up to 263 € per year.

Differences in the monetization for all designs were found in the amortization period in relation to the swap body reference model. The workshop-participants agreed that for all three designs of the MSB, an amortization period of ten years is realistic in contrast to an amortization period of six years for a swap-body. For the monetization, a linear depreciation is assumed. In order to calculate the benefit due to a longer lifetime, the acquisition costs of the MSB designs are needed. Given an interest rate of 6 %, an amortization rate of 3533 € per year can be calculated for the swap-body over six years. In contrast the longer life time of the three MSB designs lead to less annually amortization costs. This results in a monetary benefit of 1095 € for the FalaEC-Box, 607.40 € for the Shoe-Box and 119.80 € for the AirTech-Box.

The identification of cost aspects showed that there are also common aspects over all three designs. However in contrast to the common beneficial aspects, most of the costs aspects differ in the monetary value assigned to them. The reason for this is that all designs are developed to fulfill the same defined requirements leading to the same monetary values. However this is realized by different technical concepts leading to different monetary values for the cost aspects. As one main cost aspect repair costs were identified by the workshop-participants. For the Fala-EC-Box as for the Shoe-Box the repair costs were classified as direct costs with a low probability. As the AirTech-Box possesses more technical components, the probability of failure was rated medium. For the monetization it was assumed that over the lifetime of ten years all movable parts of a MSB need to be renewed once. The monetary value of the moving parts in a MSB-design was set to the difference in acquisition costs of each design relative to the swap-body. Hence, the annually averaged repair costs of 1220 €, 300 €, 760 € arise for the AirTech-Box, the Fala-EC-Box and the Shoe-Box respectively. Next to the repair costs, general maintenance costs arise on a yearly basis. For the Fala-EC-Box and the Shoe-Box the same efforts are required as for the swap-body. Again, due to the greater number of technical components of the AirTech-Box, higher costs for maintenance, namely 240 € per year, arise.

On the other hand the AirTech-Box faces no issues overcoming a low sill due to its lifting device. However, the Fala-EC-Box and the Shoe-Box need specific modifications to the chassis. These modifications were monetized in the workshop with 5000 €. When taking a lifetime of six years and given the fact that four MSBs can be handled with one chassis, "low sill" costs of 208 € occur. The participants rated this cost aspect as difficult to ascertain with low probability of occurrence.

In the course of the workshop other benefit and cost aspects were identified and partly monetized which were not described above as these aspects only have a marginal effect on the general statement of the value oriented cost-effectiveness estimation.

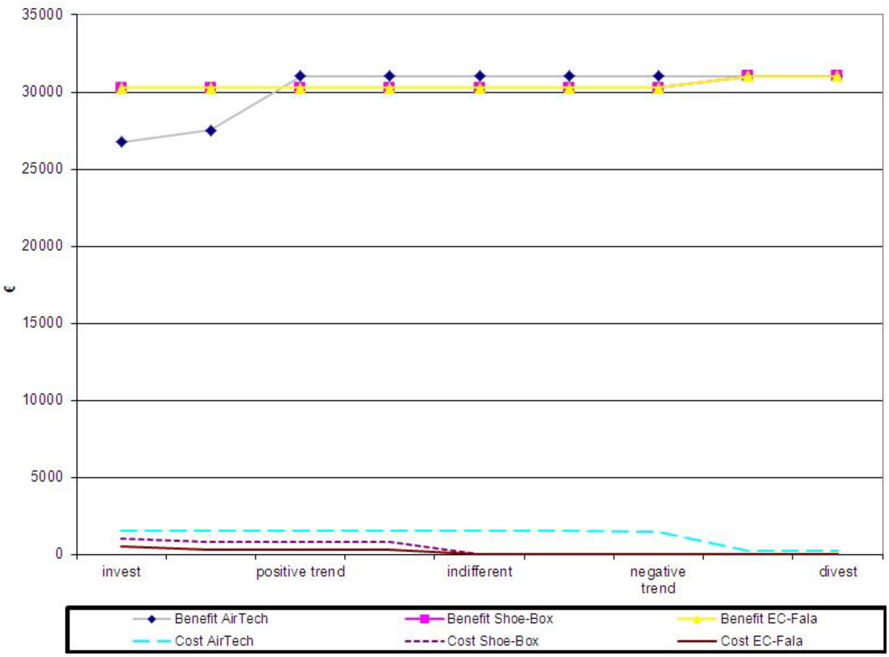

Fig. 6 NOWS-graphs of the three regarded solutions

4.3 Results of the Value Oriented Cost-Effectiveness Estimation

Figure 6 illustrates the resulting NOWS-graph for the three designs named "AirTech-Box", "Fala-EC-Box" and "Shoe-Box" respectively. All graphs show a positive run regarding the benefits and costs right at the beginning.

After evaluating the results of the NOWS-method it can be stated that an investment for any MSB can be recommended. However, the evaluation of the results leads to the following order of profitability: The Fala-EC-Box seems to be the most profitable solution, the Shoe-Box the second most profitable one and even less profitable the AirTech solution. Despite this order the difference between the solutions is almost insignificant. Therefore a decision on one of the presented designs should not be based on the calculated profitability.

5 Conclusion

Within this investigation, an estimation of the value oriented cost-effectiveness was conducted for three alternative designs of the MSB. Participants of the workshop were members of the project consortia of TelliBox. The cost-effectiveness was evaluated for each design relative to today used swap-bodies.

Generally it could be shown that the benefits for each design strongly dominate the costs independent of the risk attitude of the decision maker. This means that even when all costs of any type and with any probability are aggregated and compared with only direct benefits with a high probability, the benefits still exceed the arising costs.

Due to the positive profitability and in particular the insignificant difference of the calculated profitability of all three solutions the decision on one MSB was based on the usability of the concepts. Therefore an usability study for the three concepts was conducted. The several usability aspects of this study militated in favor of the Shoe-Box solution that was therefore further developed.

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Occupational Safety and Health as an Innovation Driver

Ingo Leisten, Ursula Bach, Frank Hees

Abstract Improving working conditions and promoting employees' motivation and ability to perform boosts capacity for innovation and corporate competitiveness. The Preventive Occupational Health and Safety funding priority of the German Federal Ministry of Education and Research (BMBF) has established a platform to address the challenges of the modern work environment from the perspective of occupational health and safety policy. Demographic change is influencing general conditions, and Preventive Occupational Health and Safety needs to be repositioned accordingly. The integration of health and safety into work practices and the support of cross-company stakeholders are prerequisites for successful integration of prevention within companies. This article discusses the relationship between capacity to innovate and prevention in terms of the current dilemmas surrounding the potential for innovation (cf. Sect. 1). These dilemmas characterize the challenges addressed by the Preventive Occupational Health and Safety funding priority and its focus groups (cf. Sect. 2). To this end, the findings of the focus groups vis-à-vis the respective issues are presented in summarized form (cf. Sect. 3). Based on the approach of "Taking prevention forward", the research results are summarized and the potential of prevention as a field for future development explored in the "Aachener Impuls zur betrieblichen Gesundheitsförderung und Prävention in der modernen Arbeitswelt" ("Aachen Impulse on the promotion of occupational health and prevention in the modern work environment"). The article concludes by presenting the funding priority within the context of European prevention strategies.

Key words: Transfer, Innovation Abilities, Prevention, Work Environment Design

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1 Capacity to Innovate and Prevention

The pressure to innovate and the highly dynamic nature of the work environment demand high flexibility, autonomy and networking, on the part of not only companies, but also staff. Demographic change poses an additional challenge for companies, in that they need to ensure their employees remain fit for work for as long as possible. The pace of change and the associated flexibility that these demands are leading to a transformation in people's career paths and learning behavior. The fact that all areas of production and service are becoming increasingly knowledge- and skill-based means that requirements for processes and structures are becoming more demanding. People are constantly required to relearn and retrain, both at individual and organizational level. The key to overcoming these challenges lies in developing the capacity to innovate at individual, organizational, network and societal level while taking into account the relevant interdependencies.

The importance of the physical and mental health of employees is often stressed as a key factor for innovative capacity, citing the maxim "a healthy employee is an innovative employee". Motivated and committed employees are a company's guarantee of competitiveness and innovative capacity [Joc]. To maintain the physical and mental health of employees, therefore, employment research has for a long time been developing comprehensive occupational health and safety concepts. Healthcare management and consulting-based promotion of occupational health have become a common feature in German companies. Benefits are being gained from this in terms of business management and personnel management, for example through the regulation of absences due to illness or through efficiency-boosting programs, and these are being systematically incorporated in work practices [Zah10]:

> Economic requirements and social obligations to create safe and healthy working conditions are not inherently opposing, but rather complementary, factors ([Bul99]; Translated by author).

However, sustainable integration of health and safety in work practices, particularly based on proactive, innovation-friendly prevention, and support for cross-company stakeholders in reorienting their tasks has in many cases not yet been achieved [Zah]. The health policy challenges within a highly dynamic work environment and ongoing demographic change make this particularly urgent. An increase in innovations that promote competitiveness in business calls for a future-focused approach to occupational health and safety, which is much more far-reaching than simple health promotion and classic safety measures. The aim is to ensure sustainable structuring of jobs and working conditions that not only satisfies the demands of business but also meets the needs of individuals [Joc]. This can realize synergies between companies' efficiency objectives and individuals' requirements to produce good work. The potential that can be unleashed through prevention needs to be recognized and companies given the means to harness it [Bul99]. Measures for Preventive Occupational Health and Safety can then make an elementary contribution to boosting the capacity for innovation and can even define workplace innovation strategies, which are a key competitive factor [Joc]. The "Preventive Occupational Health and Safety"

BMBF funding priority, which supports 18 cooperative projects with a total of 52 subprojects and nine individual projects, focuses on developing and communicating future-focused, application-oriented concepts for prevention in the workplace. Within the individual projects, diverse research results and solution proposals are compiled by various research institutes, companies, stakeholders from chambers of commerce, associations, intermediaries and special interest groups [PT 08]. This funding priority contributes to competitiveness in business by:

- Counteracting economic loss caused by lack of prevention
- Taking account of the changes in the modern working environment [Bun05] and
- Supporting the intermediaries in their role as service providers [Bun06].

Prevention plays a multidisciplinary role within the framework of the BMBF funding program "Arbeiten – Lernen – Kompetenzen entwickeln. Innovationsfähigkeit in einer modernen Arbeitswelt" ("Working – Learning – Developing Skills. Potential for Innovation in a Modern Working Environment"), and therefore also within the hightech strategy of the German federal government [Bun]. Health and safety cfat work and good working conditions thus become a "constituent requirement for innovation policy" ([Zah10]; Translated by author) based on a comprehensive innovation concept that is not restricted to technological developments.

2 Prevention in a Modern Work Environment

Companies and their employees today have to continuously adapt to rapid changes. These are characterized by increased competitive pressure, ever shorter product and innovation cycles, globalized division of labor and the delocalization of work. They need to bundle all their resources in order to survive on a globalized market, ensure their capacity for innovation and thus maintain their competitiveness over the long term [HLBH]. The more the technical possibilities expand and the faster the work environment changes due to globalization, the more challenging it becomes to implement an innovation-friendly occupational health and safety program [Zah10]. "If one of the foundations underlying Germany's capacity to innovate is 'sustainability of work', then this is one of the most urgent problems" ([MLS07]; Translated by author). The sphere within which businesses operate appears to be increasingly plagued by dilemmas. These dilemmas stem from socio-economic tensions characterized by today's working and living environment [TSHJ]. Against this backdrop, companies and the people working for them face complex decisions. Trantow et al. (2010) identify as "dilemmas for innovative capacity" those dilemmas that affect and influence the recursive levels "individual, organization, network and society" on the road to innovative capacity and global competitiveness (cf. ibid.):

- Responsible handling of human resources vs. cost pressure
- Long-term strategies for increasing innovative capacity vs. pressure to succeed
- Time for learning processes vs. time pressure
- Need for stabilization vs. pressure to be flexible.

As the results of an international expert survey also show, the work environment is increasingly faced with the challenge of performing work services fast, cheaply, in high quality and with the maximum of variability in order to remain competitive [BSH10]. These pressures to which the stakeholders in the modern working and living environment are subject can be attributed to the over-arching meta-dilemma of sustainability vs. short-term profit expectations – i.e. the conflict between economics and ecology. Prevention measures and strategies operate within this very context. Prevention should "be measured according to whether it contributes to the development of a company's potential, to its ability to adapt to changes" ([Vol07]; Translated by author).

As part of a foresight process [CGW09], a need for action was demonstrated in three key areas: On the one hand, the significance of the traditional standard work and employment model is decreasing due to the increase in flexible and atypical forms of employment, combined with a further segmentation of work and the labor market. In addition to the new risks that this entails, Preventive Occupational Health and Safety needs to address the developments with solutions appropriate to the situation. Occupational science findings cannot easily be applied to new forms of employment, e.g. in the IT industry, and are not suitable for the specific situations [MLS07]. A second area where action is needed stems from the increased desire for self-management and individual responsibility by employers and the self-employed. For employees, this means more freedom to act on the one hand, but also new risks on the other [Zah]. Self-management and self-regulation skills need to be built up in order to maintain individual employability. Thirdly, the ever-changing general global conditions are posing challenges for Preventive Occupational Health and Safety. More regional concepts are required as well as the involvement of professional organizations that have not to date been active in the field of occupational health and safety [Zah]. Traditional occupational safety is primarily determined by normative requirements and by a causal logic and approach based on safety-related and/or occupational healthcare. However, this description is inadequate for Preventive Occupational Health and Safety [Bul99]. New challenges for Preventive Occupational Health and Safety are emerging from the above-mentioned developments in the modern working environment and new research questions are being formulated for the research community. As early as 2005, in its BMBF 2005 publication, the BMBF addressed some of these questions to the funding priority that was to be set up with its focus groups [Bun05]:

Integration of prevention in workplace innovation strategies

a) To enable health potential to be harnessed as an element for promoting innovation and competition, measures must be demonstrated that incorporate preventive work design in companies' economic action strategies and the cost-effectiveness of these measures must be quantifiable in practice. The aim is to optimize the relationships between work culture, productivity and health.
b) The increasing flexibility is to be counterbalanced by strategies to over-come psychological pressure and to build up individual resources. These strategies should

exert a positive influence at individual level and in terms of technical and general organization.

c) A further aim is to promote the development of comprehensive management concepts that integrate prevention into the routines of an organization as an element of workplace innovation management, and that highlight the special role of managers in companies' prevention cultures.
d) The challenges of demographic change emphasize the need to establish demographic-related prevention, particularly with regard to mixed-age workforces (diversity).

New stakeholder alliances in the field of prevention

a) In the knowledge economy, prevention and health promotion in the workplace must be structured according to the changing requirements of the modern work environment. Within the knowledge economy, particular focus is to be placed on companies in the IT industry, for example, and professional and industry associations in the IT sector are to be won over to prevention issues.
b) Employees' extensive rights of involvement are to be actively utilized for prevention and health processes by promoting their (prevention) skills and enabling organizational learning processes (giving particular consideration to the management culture).
c) The support of prevention service providers in implementing preventive organizational and work design aimed at health promotion, and in situations involving the cooperation of various cross-company stakeholder groups, requires the formation of new stakeholder alliances. Prevention stakeholders are therefore to develop new service networks to enable the individual partners to boost their own capacity for innovation.

New transfer pathways for prevention

The transfer of prevention knowledge must be guaranteed by specific measures, and insights into the success of these measures obtained. This refers to not only the broad impact, but also the setup and development of suitable communication pathways between the parties involved with regard to the success of the cooperation.

3 The Funding Priority as a Solution Space

3.1 Innovative Funding Structures

When authorizing the funding priority, the Project Management Agency in the DLR (German Aerospace Center) and the BMBF introduced innovative funding structures that extend beyond the cooperative projects: focus groups[1], the StArG (Strate-

[1] Focus groups combine four to six projects that deal with the key content of the funding priority.

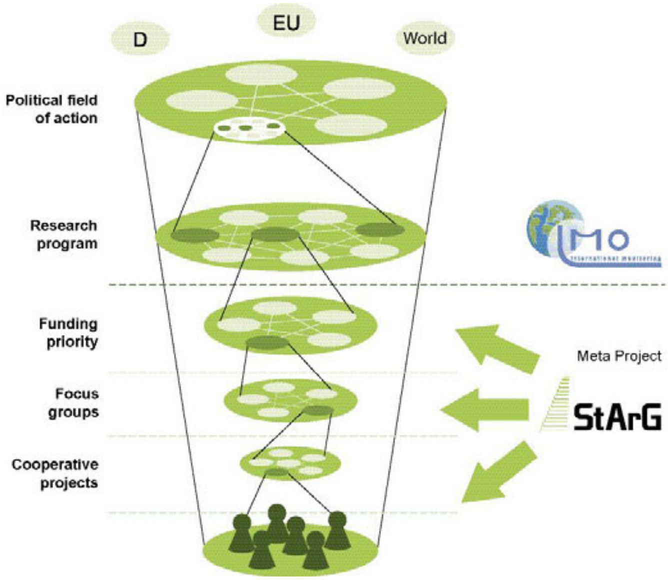

Fig. 1 Innovative funding structures in the BMBF program "Working – Learning – Developing Skills. Potential for Innovation in a Modern Working Environment"

gic Transfer in Occupational Health and Safety) Meta Project[2], the funding priority itself and the IMO monitoring project[3] were introduced as transfer and learning instruments (cf. Fig. 1).

Collaborative knowledge exchange and knowledge production, which had been publicized through various activities and media in terms of transfer, took place at these levels [HLBH]. Through bundling, systematizing and concentration of the various project stakeholders and by using targeted communication channels, new stakeholder and institution groups were identified as target groups and addressed. The external visibility of the research community was thus successfully enhanced. Thanks to the collective research in the focus groups and interaction at the level of the funding priority, stakeholders from diverse academic disciplines, different industries and the various target groups were able to develop an inter- and transdisciplinary research community for Preventive Occupational Health and Safety [BLHJ10]. To promote interaction and knowledge exchange/knowledge production processes within the funding priority, a comprehensive online work system was piloted – the iDA (interactive work and discussion platform) – which will be made available to all funding priorities within this field in future following its successful rollout. The Preventive Occupational Health and Safety funding priority gathers knowledge on how

[2] The Strategic Transfer in Occupational Health and Safety (StArG) Meta Project was authorised to support the transfer activities and network management of the funding priority. The remit of the transfer project is to provide services for the funding priority and carry out research into broad and deep transfer.

[3] For more detailed information on this, see Zettel/Haarich in this volume.

prevention affects the promotion of innovation, based on a wealth of well-founded research results and practical experience. This knowledge is accumulated using various methods and validated in numerous industries and fields of practice. The way in which the membership of the focus groups is composed allows the interrelationships between the content of particular projects to be formulated. The intentionally diverse stakeholders in the projects are actively supported by network management. The StArG Meta Project is responsible for further development and structuring of the network management [BLHJ10]. The results of the discussions, academic discourses and methodological discussions of the individual focus groups are compiled in pamphlets. These represent a collection and concentration of the academic content of the individual projects pertaining to the topics addressed by the focus group. Each of the focus groups condenses its theses and outlines research desiderata in policy documents. Selected topics and content of the focus groups, taken directly from the policy documents and pamphlets, are presented below.

3.2 Prevention as an Element of Workplace Innovation Management[4]

Qualified, healthy and efficient employees are the key to developing and implementing new products and services in a globally competitive environment. Potentially effective workplace health promotion within the context of workplace innovation management pursues this aim by utilizing the tried-and-tested prevention strategies of situational and behavioral prevention within a systematic framework. Healthcare management has become an established organizational concept for larger organizations, while smaller organizations use a systematic management and organizational model incorporating external, cross-company stakeholders. The promotion of individual and structural resources needs to take place alongside this. The passive protection concept for reducing or eliminating risks and stress is jux-taposed by a salutogenic concept for promoting individual responsibility and resources. In this model, the protection concepts are complemented by the individual or group-specific resource orientation, the health promoting effect of which has been demonstrated. The ongoing dynamism and ever growing complexity of workplace processes are also increasingly causing mental stress and diseases, which should be addressed

[4] Instruments and strategies for workplace health promotion as part of workplace innovation management are to be maintained through the respective projects of the focus group: IMMMA – Interaktive Module zur Umsetzung der Maschinenrichtlinie in der Entwicklung und Nutzung von Anlagen und Maschinen (Interactive modules for innovative implementation of the EU Machinery Directive) (www.immma.net), Inope – Netzwerkbasierte Gesundheitsförderung und Prävention in der Finanzverwaltung (Network-based Worksite Health Promotion and Prevention in the German Tax Administration) (www.inope.de), PräGo – Präventives Gesundheitsmanagement durch integrierte Personal- und Organisationsentwicklung (Preventive healthcare management through integrated personnel and organisational development) (www.praego.net) and Noah – Nutzenoptimierter und kostenreduzierter Arbeits- und Gesundheitsschutz in Handwerksbetrieben (Benefit-optimised and cost-effective occupational health and safety in handicrafts businesses) (www.noah-projekt.de).

with suitable health promotion measures. These measures are be structured according to risk group and should be gender- and life-phase-specific in nature in order to promote health, fitness for work, life expectancy and individual resources [hen10a].

3.3 Prevention as a Competitive Factor[5]

This focus group deals with the question of how and under what conditions measures for Preventive Occupational Health and Safety can make a relevant contribution to the competitiveness of businesses above and beyond pure cost aspects. It has been demonstrated that integrating human and social aspects into corporate strategy has a considerable influence on economic success and therefore the competitiveness of a company. An integrated approach to occupational health and safety affects both the performance and the motivation of employees, and can therefore make a lasting contribution to the positive economic development of companies. The economic benefits of prevention strategies become clear when the relationship between healthcare management and performance-related results at company and employee level is highlighted. The development of performance indicators enables companies to assess the actual current status of occupational health and safety in compressed form, on the basis of which cross-company benchmarking can also be initiated. Furthermore, this benchmarking triggers subject-related exchange between the companies which fosters the establishment of communication networks. Insights and practical aids to action provide companies with a comprehensive overview of their own occupational health and safety for the first time from the perspective of occupational science, occupational healthcare, personnel management, psychology, resource orientation and controlling, and clarify the effects of occupational health and safety on productivity and performance [hen10e].

3.4 Innovation Strategy and Health[6]

The thematic framework of this focus group is based on the conditions for occupational health and safety in the knowledge economy. As a leading industry, the IT sector is especially affected by the changed requirements of the modern work environment: extreme knowledge dynamics, flexible forms of employment, job nomads,

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[5] Specific results and findings on this topic can be found in the relevant publications by the PARSAG projects – Partizipatives Systemisches Arbeits- und Gesundheitssmanagement (Participative systematic work and healthcare management) (www.parsag.cbm-ac.de), PAGSmonitor – Ökonomischer Arbeitsschutz durch Benchmarking (Economical occupational safety through benchmarking) (www.pags-monitor.de) and BiG – Benchmarking in einem Gesundheitsnetzwerk (Benchmarking in a health network) (www.projekt-big.de).

[6] The current state of research in this subject area and development needs in the IT and software industry for Preventive Occupational Health and Safety are demonstrated by the following projects: GemNet – Vernetzung und Steuerung des betrieblichen Gesundheitsmanagements (Networking and control of workplace healthcare management) (www.gemnet.de),pragdis – Präven-

temporary employment contracts, diffuse places of work, blurring of the boundaries between work and private life etc. As well as causing an increase in health risks, these factors also highlight the limitations of current prevention concepts. The projects' studies show that knowledge-economy employees whose health is affected are less motivated, less committed and less innovative. To ensure the competitiveness of the industry, effective strategies must be developed to cope with mental demands and build up individual resources. Selective interventions in cases of mental stress (either at individual level only or at organizational level only) are often fruitless, since they do not address (autonomy-oriented, operationally disconnected) employees, mobile workers or freelancers. For this reason, and also in order to systematically implement prevention in workplace healthcare management, interaction between people, situations and organizations needs to be optimized in a targeted manner. These strategies need to take into account the fact that the SMBs in the industry, which represent more than 80 percent of companies, often lack the organizational structures needed to implement workplace health promotion measures. Promoting personal resources and individual responsibility, internal interaction aimed at forming interfaces, development of customized solutions by the involved parties on site and the creation of external, integrated prevention centers can exert a crucial influence [hen10c].

3.5 Health Promotion in the Context of Demographic Change[7]

Workplace health promotion in the context of demographic change requires the development and valorization of human resources throughout working life. This entails dovetailing of operational, social and individual responsibility for health. De-

tiver Arbeits- und Gesundheitsschutz in diskontinuierlichen Erwerbsverläufen (Preventive Occupational Health and Safety in discontinuous career paths) (www.pragdis.de), ITG – Präventiver Gesundheitsschutz in der IT-Branche (Preventive Occupational Health in the IT industry) (www.uni-due.de/~sx0172/cms/startseite.html), PräKoNet – Entwicklung von Präventionskompetenz in ITK – Unternehmen durch gezielte Vernetzung der Akteure (Development and prevention competence in ITC companies through targeted networking of stakeholders) (www.praekonet.de) and PRÄWIN – Prävention in Unternehmen der Wissensökonomie (Prevention in companies in the knowledge economy) (www.projekt-praewin.de).

[7] The Demopass projects – effects of match/mismatch between aspects of human and social capital, corporate strategy and work organisation on physical and mental health in the workplace, DiWa-IT – Demografischer Wandel und Prävention in der IT (Demographic change and prevention in IT) (www.diwa-it.de), TAQP – Technologieinnovation, Arbeitsorganisation, Qualifizierung, Prävention – Systematisches Handlungskonzept für Produktivität und Gesundheit (Technology innovation, work organisation, qualification, prevention – systematic action concept for productivity and health) (www.taqp.de), MeGa Wandel – Menschen- und alter(n)sgerechte Gestaltung der Arbeit – Gestaltung des demografischen Wandels in einem Unternehmen der Abwasserbranche (Person-centred and age(ing)-oriented work design – structuring demographic change in a company in the wastewater industry), LEGESA – Lebenslang gesund arbeiten (Life-long health in the workplace) (www.lebenslang-gesund-arbeiten.de/), GeFüDo – Gesundheitsorientierte Führung im demografischen Wandel (Health-oriented management in the context of dedemographic change) demonstrate concepts and instruments for prevention under the conditions created by demographic change.

mographically oriented health promotion requires an increased prevention element, since all the operational and individual aspects relating to the stress situations of employees can only be accounted for and structured by using an integrated approach. Only by matching workplace services with individual needs and requirements can prevention of this type become effective. The integration of prevention in workplace fields of action is becoming essential, in order to allow for the effects on the health of the involved parties when designing work systems and processes – i.e. a foresighted, preventive and driven approach to work design. A society undergoing demographic change needs to see its working environments increasingly as learning environments. Continuous training and learning at individual and operational level establishes the initial prerequisites for living and growing old in good health, which in turn increases and supports fitness for work. A workplace culture where appreciation is expressed can help to promote health. The integrated approaches of the focus group's projects show that prevention under conditions of demographic change is not solely the task of safety professionals, ergonomists or occupational health practitioners. All stakeholders who create and shape workplace structures and processes, as well as cross-company health promoters, are being called upon to help implement the available approaches, instruments and procedures and adapt the respective requirements [hen10b].

3.6 Participation, Leadership and Prevention[8]

This focus group researches the way in which Preventive Occupational Health and Safety relates to the participation of employees, the role of managers and innovative work design. Classic prevention guidelines often include standardized codes of conduct, and prevention measures are experienced by employees as a burden in some cases, extending in many cases beyond the work environment to private life, and are seen as rules imposed "from outside". The concept of participative prevention for occupational health and safety structuring processes can fulfill a crucial intermediary function between the objective nature of prevention requirements and personal structuring requirements. The employees are seen as work-design and organization specialists, and must empower themselves to protect their own interests and set their own goals. In this approach, participation is successful

[8] Concrete case studies for implementation and generalised examples can be named for the basal aspects of participative prevention from the experiences of the 3P projects – Partizipative Präventionskompetenz Pflege (Participative prevention competence care) (www.alice-3p.de), PaPsD – Partizipative Prävention im Arbeits- und Gesundheitsschutz durch sozialen Dialog (Participative prevention in occupational health and safety through social dialogue) (www.papsd.de), Quiero – Qualifizierung durch Integration erfahrungsbezogener Ressourcen in Organisationen der Pflege (Qualification through integration of experience-related resources in care organisations) (www.quiero-online.de) and PARGEMA-Partizipatives Gesundheitsmanagement (Participative healthcare management) (www.pargema.de).

- when it promotes a process of (innovative, modernizing) organizational development that serves to reorganize the prevention and participation objectives,
- when management structures and behavior are redetermined through their interaction with the participation requirements,
- and sustainable, when it has stable procedures within which it can develop dynamically on a long-term basis.

Participation therefore allows prevention objectives to be acknowledged as having equal value and status to economic objectives. Management behavior and a culture of trust within the company are regarded as very important for social (i.e. evaluative, emotional, instrumental and information policy related) support of participative prevention processes [hen10d].

3.7 Cross-Company Alliances[9]

The projects' studies show that there is a major need to address issues concerning prevention and occupational health and safety in the workplace, and that this stems from current requirements and problems rather than "classic" fields of activity relating to occupational safety. The studies indicate that potentially effective prevention strategies call for more emphasis to be placed on specific (regionally oriented and industry-specific) action requirements of SMBs rather than on unilateral, normative messages. For various reasons, this need for innovative, practicable prevention concepts is not greatly heeded or addressed by occupational health and safety institutions. However, the functions of associations, chambers of commerce and trade organizations such as training, information, consulting, exchange of experiences and industry dialogue offer strategic potential for prevention, which needs to be harnessed and developed. Because human and material resources are often limited, however, this will only be successfully achieved if the ability and will to cooperate increases on all sides, sometimes through new forms of collaboration. Greater, continuous cooperation and networking of chambers of commerce, associations and occupational health and safety service providers and institutions, when built on correspondingly sustainable structural foundations, can improve in particular the standard of information and the availability of consulting services. For both

[9] The PräSend projects – Betriebliche Prävention durch Service Engineering und Dienstleistungsmanagement (Prevention in the workplace through service engineering and service management) (www.prae-send.de), PräTrans – Transferpotenziale der Kammern und Fachverbände für gesundheitliche Prävention in Klein- und Ein-Personen-Unternehmen (Transfer potential of chambers of commerce and professional associations for health-related prevention for small companies and sole traders) (www.gesundheit-unternehmen.de), Inno GeMa – Netzwerkentwicklung für innovatives Gesundheitsmanagement (Network development for innovative healthcare management) (www.innogema.de) and Neu Prag – Neue Präventionsallianzen für mehr Gesundheit in KMU der Baustoffindustrie (New prevention alliances for improving health in SMBs in the construction materials industry) (www.neuprag.de) are developing innovative prevention strategies for small and medium-sized businesses with an emphasis on establishing sustainable networks with intermediary organisations and companies.

the development of prevention instruments and the transfer of products and services to practical applications, businesses and networks need to be involved so that prevention in the workplace is increasingly regarded as being dialogue and service based [hen10f].

3.8 Strategic Transfer in Occupational Health and Safety

With regard to transfer communication in the field of prevention, the combination of measures for broad and deep transfer can help to optimize the transfer problem. These measures enable the explicit forms of knowledge to be mapped in a publicly accessible way through broad transfer and communicated with the help of methods adapted to the target group (mostly in a media mix). Interactive methods of deep transfer, however, appear more effective for the development of implicit knowledge [HLB10]. Successful deep transfer at project level requires systematic development of communication and cooperation by the relevant prevention stakeholders and as part of company procedures, so that the requirements, interests and target systems of all parties involved in the cooperation can be taken into account. For transfer into work practices, prevention must be derived from a company's needs or benefits. Transfer must not simply be aimed at conveying superficial information, but must identify opportunities for collective knowledge production and sustainable integration in practice, in order to fulfill the respective individual and organizational needs.

4 Taking Prevention Forward

At the annual meeting of the funding priority in 2009, the "Aachener Impuls zur betrieblichen Gesundheitsförderung und Prävention in der modernen Arbeitswelt" ("Aachen Impulse on the promotion of occupational health and prevention in the modern work environment") [hen] perspective document was consolidated and approved. This Impulse (cf. Fig. 2) summarizes the research results and future potential of the "Preventive Occupational Health and Safety" field of research. The content was discussed by the meeting participants, who came from the academic and business communities as well as associations, chambers of commerce, intermediaries and special interest groups, and underpinned by the focus groups of the funding priority through the drafting of policy documents with the latest research results from the individual projects. The Impulse is a strategic policy document. The fact that the Impulse was widely discussed in the run-up to the meeting and collectively approved during the event not only enabled the definition of a status quo for conducting research, but also the establishment of a shared perspective on the future.

The Aachen Impulse

"Realign Prevention Research – Strengthen Innovative Ability"

Innovative ability in Germany as work and business venue with its technologies, its efficient and competitive enterprises and its competent people needs workplace health and safety schemes and humane work design sustainably embedded in practice.
Occupational safety and health encompasses work and organizational design aimed at advancing and protecting people as well as a personnel and competence development that also provides for life beyond work. It aims at preserving creativity and employability of people in a working environment that is characterized by dynamic, networked forms of work in the face of demographic change.
After three years of cooperative work, scientists, entrepreneurial actors and prevention service providers conclude:

Research on Workplace Health and Safety

- strengthens innovative ability,
- fosters participation and creativity,
- fosters potentials in modern work environments,
- supports innovative human work design,
- requires service-oriented and cooperative actors.

Research results document the possibilities and necessities of workplace health and safety schemes. In order to continue this successful path, further targeted promotion of interdisciplinary research and fostering of young academics is required. The results of this field of research show further research requirements:

Participation and Leadership for a Proactive Work Design

- Strategies, models and instruments making participative prevention an integral part of leadership and organizational culture,
- Ambivalent relationship of participation and leadership,
- Framework conditions to foster the ability to adapt change,
- Innovative approaches to participation for prevention in changing corporate and learning cultures.

Prevention for Quality Improvement of Work and Life

- Models for creativity-inducing and age-appropriate employment vitae,
- Change management for a positive shaping of interactions between work life and life beyond work,

Preventive and Innovative Corporate and Learning Cultures

- Correlations between organizational and learning cultures, prevention and innovation,
- Continuous learning processes regarding prevention and innovation as integral parts of corporate culture,
- Preventive work cultures beyond corporate borders.

Prevention to leverage Sustainable Corporate Policies

- Models for corporate policies with proactive risk management,
- Concepts and criteria for corporate assessment and for corporate leadership creating value(s),
- Combination of prevention and Corporate Social Responsibility (CSR).

Innovative Prevention Alliances

- Regional approaches and attracting new actors in order to reach small enterprises in particular
- Cooperative skills of actors
- Marketable transfer strategies
- Process-oriented and integrated proposal of services.

**Deploy proactive measures in Occupational Safety and Health–
Research and Business in Dialogue –
Cooperative Acting and Learning Together**

Förderschwerpunkt
Präventiver Arbeits-
und Gesundheitsschutz

Fig. 2 Aachen Impulse: Realign Prevention Research – Strengthen Innovative Ability

Through the construct of the funding priority with its specific structures and processes, it is possible to pass on condensed information, e.g. in the form of the Aachen Impulse, to the IMO monitoring project and the Learning Program [BLHJ10]. Thanks to this and because of the discussion of the Impulse by the International Panel of the monitoring project, the findings at national level are being incorporated in international discourse and the research results can be integrated in the relevant European prevention strategies. At European level, prevention issues are being addressed in the research network for work design, working conditions and occupational health and safety within the ERANET program of the European Commission. For these activities, "the future sustainability of a modern working environment and the question of how to position research and innovation policy within this context" ([Zah]; Translated by author) play a key role. According to the "Luxembourg Declaration on Workplace Health Promotion", the promotion of physical, mental and social wellbeing at work and the development of skills, competence and a sense of responsibility must be addressed through coordinated measures [Eur]. This is to be achieved by improving working conditions and work organization and by promoting active staff participation through the cooperation of employers, employees and society (ibid.). As well as the more technical matter of optimizing working conditions, the funding priority has also made it possible to define approaches to structuring prevention-oriented organizational and personal development. The joint declaration of the 18th World Congress on Safety and Health at Work in Seoul (2008) formulated an orientation framework as follows:

> The right to a safe and healthy working environment should be recognized as a fundamental human right; education, training, and the exchange of information and good practices are highly important in this context (...); and governments and all other stakeholders, i.e. the social partners and professional safety and health organizations play an important role in this (quoted according to [Zah]; Translated by author).

The declaration states:

> Promoting high levels of safety and health at work is the responsibility of society as a whole and all members of society must contribute to achieving this goal by ensuring that priority is given to occupational safety and health in national agendas and by building and maintaining a national preventative safety and health culture. (ibid, 5; Translated by author).

Through the research and development of practical and scientifically founded solutions, the "Preventive Occupational Health and Safety" funding priority is developing important prerequisites and orientational incentives which enable the relevant stakeholders to make prevention an integral part of their activities. Being firmly embedded within the national hightech strategy and international health and safety requirements, the "Preventive Occupational Health and Safety" funding priority offers methods and results that address the challenges and dilemmas of the modern work environment. Examples of good practice have been developed through experience gained from business practices. It has been shown that the concept of prevention can be successfully integrated in corporate activities. The development and consolidation of a Preventive Occupational Health and Safety research community ensures that these issues and questions are addressed in society over the long term.

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Strategische Transferkommunikation von Innovations- und Forschungswissen

Ingo Leisten, Frank Hees

Zusammenfassung Die Schnittstelle zwischen Wissenschaft und Praxis gewinnt in Zeiten, in denen sowohl Innovation als auch Nachhaltigkeit zu den wesentlichen Faktoren im gesamtwirtschaftlichen Wettbewerb zählen, zunehmend an Bedeutung. Zahlreiche Forschungsdisziplinen beschäftigen sich mit der Entwicklung innovativer wie nachhaltiger Lösungen und Verfahren für die unternehmerische Praxis, doch oftmals schlägt ein zielgruppengerechter und handlungswirksamer Transfer von Innovations- und Forschungswissen fehl. Dieser Beitrag beschreibt anhand eines Fallbeispiels zu Forschungsprojekten des Präventiven Arbeits- und Gesundheitsschutzes, wie die Rollen von Forschung und Praxis bei der Wissensproduktion gestaltet werden sollten, damit Transfer gelingen kann. Als eine sensible Stellgröße dazu wird die Interaktionsarbeit der Projektakteure identifiziert. Zur systematischen Kommunikations- und Kooperationsentwicklung in (Forschungs-)Projekten wird der Ansatz des Transfer Engineerings vorgeschlagen, dessen Ausgestaltung und Umsetzung im Rahmen einer qualitativen Analyse von Projekten des Fallbeispiels vorgestellt werden.

Schlüsselwörter: Wissenstransfer, Kommunikationsprozess, Prävention, Anwendungsorientierte Forschung

1 Innovation und Prävention

Unternehmen und ihre Mitarbeiterinnen und Mitarbeiter müssen sich heute schnellen und stetigen Veränderungen stellen. Diese sind durch einen verschärften Wettbewerbsdruck, immer kürzere Produkt- und Innovationszyklen, eine globalisierte Arbeitsteilung und die Entlokalisierung von Arbeit charakterisiert. Sie müssen alle

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Ressourcen bündeln, um auf einem globalisierten Markt bestehen zu können, ihre Innovationsfähigkeit zu sicher und damit ihre Wettbewerbsfähigkeit nachhaltig zu bewahren [HHL]. Dabei stellt sich die Herausforderungen für Unternehmen zunehmend in Dilemmata dar: dabei handelt es sich um sozio-ökonomische Spannungsfelder der heutigen Arbeits- und Lebenswelt [TSHJ10], die Unternehmen und die darin tätigen Menschen vor komplexe Entscheidungen stellen. Trantow u. a. (2010) identifizieren als „Dilemmata der Innovationsfähigkeit", die gleichsam „Individuen, Organisationen, Netzwerke und Gesellschaft auf dem Weg zur Innovations- und globalen Wettbewerbsfähigkeit zu bewältigen haben" (vgl. ebd.):

- Verantwortlicher Umgang mit Humanressourcen vs. Kostendruck,
- Langfristige Strategien zur Erhöhung der Innovationsfähigkeit vs. Erfolgsdruck,
- Zeit für Lernprozesse vs. Zeitdruck,
- Stabilisierungsbedarf vs. Flexibilisierungsdruck.

Diese Spannungsfelder, mit denen Akteure der modernen Arbeits- und Lebenswelt umgehen müssen, lassen sich dem übergeordneten Problemkomplex Nachhaltigkeit vs. kurzfristige Gewinnerwartung zuordnen (vgl. ebd.).

Als Schlüssel um diesen Herausforderungen zu begegnen wird oftmals der Begriff „Innovation" angeführt. Dabei engt der traditionell technik- und produktzentrierte Innovationsbegriff ein, so dass betriebliches Innovationsmanagement scheinbar ausschließlich Aufgabe von Großunternehmen und den darin angesiedelten Stabsstellen zur Forschung und Entwicklung ist. Das aktuelle Forschungs- und Entwicklungsprogramm des Bundesministeriums für Bildung und Forschung (BMBF) „Arbeiten – Lernen – Kompetenzen entwickeln. Innovationsfähigkeit in einer modernen Arbeitswelt" erweitert diese Perspektive und betrachtet Innovationsfähigkeit als Schlüsselfaktor für wirtschaftlichen Erfolg und richtet den Blick auf den Menschen und dessen Arbeitsbedingungen als entscheidende Voraussetzung zur Entfaltung von Innovation [Bun]. Demnach hängt häufig die „organisationale Fähigkeit, innovativ zu sein, (…) weniger vom technischen Entwicklungsstand eines Unternehmens als vielmehr von seinen Humanpotentialen sowie seinen internen Prozessen und Strukturen ab" [TSHJ10].

Der Innovationsdruck sowie die enorme Dynamik der Arbeitswelt, fordern eine hohe Flexibilität, Autonomie und Vernetzung, nicht nur von Unternehmen sondern auch von Beschäftigten. Zusätzlich stellt der demografische Wandel Unternehmen vor die Herausforderung, die Arbeitsfähigkeit ihrer Mitarbeiter möglichst lange zu erhalten. Die Bedeutung der körperlichen und geistigen Gesundheit von Beschäftigten, wird häufig, gemäß dem Motto „nur ein gesunder Mitarbeiter ist ein innovativer Mitarbeiter", als wichtiger Faktor der Innovationsfähigkeit betont. Zum Zweck der körperlichen und geistigen Gesunderhaltung von Arbeitskräften entwickelt die Arbeitsforschung deshalb seit langem umfangreiche Konzepte des Arbeits- und Gesundheitsschutzes. Allerdings ist eine nachhaltige Integration von Sicherheit und Gesundheit im betrieblichen Handeln, insbesondere im Sinne einer proaktiven, innovationsförderlichen Prävention, sowie die Unterstützung der überbetrieblichen Akteure bei der Neuorientierung ihrer Aufgaben vor dem Hintergrund der gesundheitspolitischen Herausforderungen einer hochgradig dynamisierten Arbeitswelt und des demografischen Wandels, vielfach noch nicht erfolgt. Eine Steigerung wettbewerbsförderlicher Innovationen in der Wirtschaft setzt allerdings einen zukunftsorientierten Arbeits- und Gesundheitsschutz, der über Gesundheitsförderung und den klassischen Gefahrenschutz hinausgeht, voraus. Im BMBF Förderschwerpunkt „Präventiver Arbeits- und Gesundheitsschutz", in dem 18 Verbundprojekte mit insgesamt 52 Teilvorhaben gefördert werden, steht die Erarbeitung und Vermittlung von zukunftsgerichteten, anwendungsorientierten Konzepten im Fokus. Als Metathemen in diesem Förderschwerpunkt lassen sich u. a. identifizieren:

- Betriebliches Innovationsmanagement,
- Prävention als Wettbewerbsfaktor,
- Innovationsstrategie und Gesundheit in der Wissensökonomie,
- Gesundheitsförderung im demografischen Wandel,
- Partizipation und Führung,
- Überbetriebliche Allianz.

2 Wie kommt das Innovations- und Forschungswissen in die Praxis?

In Bezug auf die Umsetzung der Forschungsergebnisse in das praktische Arbeitsumfeld besteht wie in vielen anderen Forschungsfeldern auch im Falle des Arbeits- und Gesundheitsschutzes allerdings ein Transferproblem. Unter diesem Transferproblem subsummiert man disziplinenübergreifend sämtliche Faktoren, die eine mangelhafte Wahrnehmung und Anwendung wissenschaftlicher Forschungsergebnisse in der Praxis bewirken [HLHJ]. Die Ergebnisse des BMBF-Metaprojektes StArG (Strategischer Transfer im Arbeits- und Gesundheitsschutz), das die aktuellen Präventionsprojekte begleitet, weisen darauf hin, dass die Transferproblematik auch im Präventiven Arbeits- und Gesundheitsschutz noch nicht abschließend gelöst ist. Praktiker beklagen weiterhin die teilweise mangelnde Praxisrelevanz wissenschaftlicher Forschungsergebnisse, Forscher bemängeln die fehlende Umsetzung der wissenschaftlichen Ergebnisse im unternehmerischen Handeln. Der Grund wird dabei oftmals im Scheitern von Transfer gesehen.

Doch was versteckt sich hinter dem Ausdruck „Transfer" im beschriebenen Themenfeld? Henning/Leisten/Bach/Hees [HLBH09] weisen darauf hin, dass es notwendiger Weise einer Spezifizierung des Transfer-Begriffs bedarf. Neben Breitentransfer, der vor allem die Stakeholder der Präventionslandschaft im Sinne von Öffentlichkeitsarbeit und (Forschungs-)Marketing ansprechen und sensibilisieren soll, geht es um Tiefentransfer, der sich insbesondere auf Projektebene realisiert. Transfer im Sinne von Tiefentransfer bezieht sich auf die kooperative Forschungsarbeit zwischen Akteuren aus Forschung, unternehmerischer Praxis und Intermediären (wie zum Beispiel Verbände und Kammern, Krankenkassen und Berufsgenossenschaften). Hier entscheidet sich, inwiefern „Produkte“ der Foschungsarbeit in der (unternehmerischen) Praxis akzeptiert, verstanden, gewollt, angewendet und weiterentwickelt werden. Dazu werden Konzepte zur Wissensgenerierung und Handlungsumsetzung benötigt, die eine kooperative Zusammenarbeit in Akteursallianzen fördern.

Unbestritten leistet der Präventive Arbeits- und Gesundheitsschutz einen Beitrag zur Stärkung der Innovationsfähigkeit [HLH09]. Innovation kann nach Kowohl und Krohn [KK00] als ein konstruktiver Lernprozess verstanden werden, der Entwurf und Verwendung umfasst. Doch diese Reziprozität des Innovationsprozesses spiegelt sich meist nicht in der Konstellation seiner Akteure wieder. Die Personen, die Innovationen entwickeln, sind häufig organisational wie fachlich unabhängig von den späteren Nutzern. Neue Produkte oder Prozesse werden in einer Forschungseinrichtung produziert, um dann über verschieden Kanäle in die Praxis transferiert zu werden. Die Gründe für die häufig mangelnde Praxisrelevanz von Forschungsergebnissen vermuten Henning et al. [HLBH09] in der prinzipiellen Divergenz zwischen den forscherischen und unternehmerischen Zielsetzungen sowie der zum Teil mangelhaften Fähigkeit der Praktiker, akute Forschungsbedarfe zu formulieren. Verstärkt wird diese Symptomatik durch die schwache Ausprägung von Rückkopplungsmechanismen, mittels derer Wissenschaftler Praxiswissen zur Ausrichtung ihrer Forschungsaktivitäten erhalten.

Auf der einen Seite steht also der Wissenschaftler mit seinem Streben nach allgemeingültigem Wissen und Erweiterung des disziplinären Erkenntnisstandes, auf der anderen der Anwender, der Interesse an einer möglichst schnellen, effektiven und kostengünstigen Lösung hat. Die unterschiedlichen Interessenhorizonte, Handlungslogiken, Verarbeitungskontexte und Alltagswelten von Forschern und Praktikern können dazu führen, dass Forschungsergebnisse nur eine geringe Relevanz im praktischen Arbeitsfeld haben [Sau05].

An dieser Stelle zeigt sich, dass strategische Transferkonzepte nicht erst bei der Vermittlung, sondern schon bei der Produktion von Wissen ansetzen müssen [HLHJ]. „Das Wissenstransferproblem beginnt bereits während der Entstehungsphase von Wissen“ [mol]. Das Spannungsfeld zwischen den verschiedenen Systemzugehörigkeiten und Handlungslogiken von Forschern und Praktikern kann nur durch ein gegenseitiges Verständnis gelöst werden, welches einen intensiven Austausch von Forschern und Praktikern erfordert. Dies setzt eine Abkehr von einem Sender-Empfänger-Denken bei der „Transfer“-Arbeit voraus [LH]: es geht nicht um die isolierte Lösungssuche von Forschung für die unternehmerische Praxis mit einem universellen Umsetzungsanspruch. Vielmehr muss die Spezifik unternehmerischer Notwendigkeiten und Rahmenbedingungen sowie das Erkenntnisinteresse von Forschung gleichberechtigt in der kooperativen Projektarbeit berücksichtig werden. Um dem Rechnung zu tragen, wird im Bereich der Anwendungsforschung zunehmend auf kooperative Methoden bei der Zusammenarbeit von Forschung und (unternehmerischer) Praxis gesetzt. Der Zusammenschluss heterogener Akteure aus Wirtschaftsunternehmen, Wissenschaftsorganisationen und Dienstleistungseinrichtungen gewinnt zunehmend an Bedeutung [Sau05].

3 Transfer Engineering – Leitlinie für Strategische Transferkommunikation

Ein Ansatz, der die daraus resultierenden Anforderungen zur Gestaltung der Kooperation der heterogenen Projektbeteiligten gerecht wird, ist das Transfer Engineering. Transfer Engineering beschreibt ein Konzept, das Gestaltungsaspekte und Methoden für eine systematische Kommunikations- und Kooperationsentwicklung zwischen Akteuren aus Forschung, unternehmerischer Praxis, Intermediären und überbetrieblichen Partnern in anwendungsorientierten Forschungsprojekten aufzeigt. Beschreibungs- und Gestaltungsdimesionen der Zusammenarbeit im Sinne des Transfer Engineerings werden in der Literatur im Rahmen von Studien zu Partizipation und Empowerment sowie aktuell zur Einbeziehung des Kunden in den Innovationsprozess diskutiert. Als bedeutender Einflussfaktor im Innovationsprozess werden Information und Kommunikation identifiziert [BDMS08]. Eine wesentliche Ursache für fehlgeschlagene Innovationen im Forschungsprozess liegt nach Scholl [Sch] in sogenannten Informationspathologien zwischen Entwicklern und Anwendern. Diese Pathologien bestehen in entscheidungsrelevanter Information, die – obwohl prinzipiell zugänglich – nicht produziert, nicht korrekt übermittelt, nicht beschafft oder nicht korrekt verarbeitet wird. Der Austausch von Information und der kooperative Wissensproduktionsprozess ist in der Forschungsprojektarbeit wesentlicher Erfolgsfaktor für das Erreichen der Projektziele und damit für den Innovationsprozess. Transfer Engineering bezieht sich ausdrücklich auf alle Phasen des Innovationsprozesses und damit auf alle Phasen der Projektarbeit. Die Zusammenarbeit zwischen Forschern und Praktikern kann sich nicht nur auf einzelne Projektphasen, wie etwa in der Erhebungsphase und in der Anwendungsphase, beziehen. Vielmehr zählen zu den phasenübergreifenden Einflussfaktoren eine gemeinsame Mission und die kontinuierliche Einbeziehung aller relevanten Akteursgruppen, um eine bestmögliche Akzeptanz aufzubauen [Pay]. Dies ist von besonderer Bedeutung, wenn meinungs-, einstellungs- und verhaltensrelevante Veränderungsprozesse auf individueller oder organisationaler Ebene durch ein Projekt angeregt werden soll, so wie es in den meisten Projekten zum Präventiven Arbeits- und Gesundheitsschutz der Fall ist.

Bisher wurde bei der Entwicklung von Produkten und Dienstleistungen in Forschungsprojekten oftmals nur der Nutzen einer der Partner berücksichtigt: entweder das Erkenntnisinteresse der Forscher oder die Anforderungen der Praxis. Vor den aktuellen Diskursen zu Innovationen durch Kundenorientierung werden Forderungen von Forschungsförderern nach stärkerer Kundenorientierung des „Leistungsangebotes“ von Forschungsprojekten laut: Forschungsprojekt-Ergebnisse sollen akzeptiert und benötigt werden, es soll Nachfrage nach den erzielten Lösungen bestehen, und Ergebnisse sollen den Erwartungen der Praktiker entsprechen.

Dabei ist „Kundenorientierung“ – d. h. in diesem Verständnis Praxis-Nähe – nicht ausschließlich auf Produkte der Forschung zu beziehen, sondern auch auf den eigentlichen Entwicklungs- bzw. Innovationsprozess. So tritt neben das Kriterium der Kundenorientierung bzw. Praxisrelevanz der Ergebnisse des Forschungsprojektes in Anlehnung an Bruhn [BH03] auch das Kriterium der Kundennähe des Interaktionsverhaltens. Doch wer ist eigentlich der Kunde in einem Forschungsprojekt? Es ist zu „reflektieren, dass nicht bloß [. . .] die Wissenschaft in ein System der Praxis, sondern auch das System der Praxis in die Wissenschaft hinein interveniert“ [HSS09]. Im Rahmen des Konzeptes Transfer Engineering werden anstelle einer Kundenbeziehung zwischen Forschung und Praxis die Begriffe Anbieter und Nachfrager verwendet. Dies betont den Austauschprozess zwischen den Akteuren der Projektarbeit: sowohl Forscher als auch Praktiker halten jeweils spezifische Leistungsangebote für den jeweils anderen Partner vor und versprechen sich vom jeweils anderen Projektpartner und von der gemeinsamen Projektarbeit spezielle Leistungen. Ziel von Transfer ist damit die anwendungsorientierte Interpretation von Information, um so gemeinsames, neues Wissen zu schaffen. Für die Forschung sind Wissen und Erkenntnisinteresse konstitutive und sinnstiftende Elemente. Doch auch die unternehmerische Seite kann nicht ohne (neues) Wissen nachhaltig wettbewerbsfähig sein; doch trotz aller Bemühungen, die Ressource Wissen entzieht sich hartnäckig jeder trivialisierenden Steuerungspraxis [NRP10]. Auch wenn der Begriff „Wissensmanagement“ seit Jahren in Theorie und Management-Praxis kursiert, sind zahlreiche Instrumente und Methoden mehr oder weniger gescheitert; es besteht weiterhin die unabdingbare Notwendigkeit für Unternehmen nach Austausch von Wissen. Nach North u. a. (2010) [NRP10] lassen sich vier Gründe anführen, die Wissensaustausch für Unternehmen immer wichtiger werden lassen: ähnliche Probleme an unterschiedlichen Orten, Wissensintransparenz, Synergien durch Erfahrungsaustausch, Wissensteilung als menschliches Grundbedürfnis. Um diesen Anforderungen zu begegnen, sind „Möglichkeiten zu schaffen, Dialoge zwischen Wissensanbietern und Nachfragern zu unterstützen, um Wissen lokal verfügbar zu machen, Problemlösungen an spezifische Kontexte anzupassen sowie fehlendes Wissen zu beschaffen, zu vernetzen und zu kombinieren“ [NRP10]. Diese Einsicht bezieht sich explizit auf den unternehmensinternen Wissensproduktions- und Wissensaustauschprozess; doch auch für Handlungszusammenhänge, in denen überbetriebliche Zusammenarbeit in heterogenen Personenkonstellationen realisiert werden, wie in den hier beschriebenen Präventionsprojekten, ist Norths Forderung unverzichtbar. Verschwimmen nun die Grenzen zwischen Anbieter und Nachfrager im Forschungsprozess, da unternehmerische Praxis und Forschung gleichsam „Kunde“ als auch Anbieter von Informationen sind, so verstehen sich die Dimensionen der Kundenorientierung aus dem Industriegüter-Kontext [BH03] bidirektional: Ein anwendungsorientiertes Forschungsprojekt weist dann Kundenorientierung auf, wenn der Entwicklungsprozess und die erzielten Ergebnisse

a) Nutzbarkeit und Nützlichkeit für die (unternehmerische) Praxis aufweisen,
b) dem Erkenntnisinteresse der Forschung dient und das Interaktionsverhalten der Beteiligten es zulässt, dass
c) Vertreter der Forschung kontinuierlich Transparenz in die unternehmerische Praxis erhält und damit zum Teil der Praxis werden und
d) Praktiker in den Forschungsprozess als Experten einbezogen werden und damit zum Teil der Forschung werden.

Je intensiver die Interaktion und die Kooperationserfordernisse zwischen Forschung und Praxis, desto besser sind die Voraussetzungen für Perspektivenübernahme und gemeinsame Wissensschaffung.

Hinsichtlich des Gegenstands der Projektarbeit können (und werden) zwischen Praktikern und Forschern gegenläufige Interessen bestehen. Oftmals sind die unternehmerischen Interessen an Präventionsthemen, wenn überhaupt ein Bedarf ausgeprägt ist, von grundsätzlich anderer Art als die der Präventionsforscher [HLBH09]. Abstrahierend lässt sich dies im anfangs beschriebenen Dilemma Nachhaltigkeit vs. kurzfristige Gewinnerwartung zusammenfassen. Aufgrund der differierenden Erwartungen ist ein gemeinsamer Gegenstand der Interaktion und Kooperation im Forschungsprozess zu bestimmen, der von allen Akteuren geteilt wird und für alle Relevanz hat. Die Akteure sollten ihr Handeln so aufeinander abstimmen, dass ein gemeinsamer Gegenstand bearbeitet werden kann [Dun] und ein kooperativer Prozess der Leistungserstellung gestaltet wird. Dies führt zu einer veränderten Rolle der Projektakteure: die Praktiker werden vom passiven Beobachtungsobjekt der Forschung zu einem Co-Produzenten der Forschungsprojektergebnisse und die Forscher vom Beobachter von Praxis zum Berater, Moderator, Begleiter und Dienstleister im anwendungsorientierten Kontext. Wenn beide Seiten lernen, sich beide als Lehrer und Schüler fühlen, entsteht ein lebendiger Wissensaustausch [NRP10]. Um eben diesen Prozess zu unterstützen, wird ein Kommunikations- und Kooperationsentwicklungsprozess zwischen den Projektakteuren im Sinne des Transfer Engineerings angeregt.

4 Interaktion als sensible Stellgröße im Innovations- und Forschungsprozess

Die Ergebnisse des Metaprojektes StArG zeigen den transferförderlichen Einfluss langfristig angelegter Transferpartnerschaften zwischen Forschung und Praxis. Entscheidender als der Einsatz von Methoden zur Informationsweitergabe und -speicherung ist vielmehr noch die gegenseitige Anerkennung der Forscher und Praktiker als gleichberechtigte Experten innerhalb der Projektarbeit. Demnach sind Kommunikations- und Kooperationsräume in der Projektarbeit zu schaffen, die die Expertise von Forschern und Praktikern gleichsam in den gemeinsamen Entwicklungsprozess einfließen lassen, um so einen Mehrwert für beide Seiten zu schaffen [Val09]. Ziel ist ein Projektsystem, das sich nach North als Wissensgemeinschaft definieren lässt. Wissensgemeinschaften sind über „einen längeren Zeitraum bestehende Personengruppen, die Interesse an einem gemeinsamen Thema haben und Wissen gemeinsam aufbauen und austauschen wollen“ [NRP10]. Wissen wird damit im Prozess der Kooperation zum Produkt der Interaktion der Personen, wobei explizite und implizite Anteile von Wissen untrennbar verbunden sind. Die impliziten Elemente von Wissen werden erhalten und weitergegeben bzw. an die lokalen Nutzungsbedingungen angepasst. Dies hat zur Folge, dass sich der Prozess weitgehend selbstgesteuert entwickelt und nur die Rahmenbedingungen geschaffen werden können, damit Wissensgemeinschaften entstehen (ebd. 2010). Das Interaktionsverhalten entscheidet über den Erfolg der Zusammenarbeit.

Michulitz [Mic05] hat gezeigt, dass Kommunikation durch ihre Ereignishaftigkeit prozesshafte Eigenschaften hat und darüber hinaus durch die Mitteilung von Entscheidungen [Luh84] in Organisationen und damit auch in überbetrieblichen Projekten strukturbildend ist. Die Grenze für die Zuordnung konkreter kommunikativer Handlungen zum Prozess oder zur Struktur der Organisation ist dabei fließend. Ob Kommunikation durch den Anschluss von Verstehen an mitgeteilte Information [Krä01] oder als Transformations- [HM92] oder Evolutionsprozess in Organisationen [Mic05] verstanden wird, so verdeutlicht jede Perspektive nach Michulitz (2006) den Charakter von Kommunikation als (Kern-)Prozess einer Organisation.

Die im Förderschwerpunkt Präventiver Arbeits- und Gesundheitsschutz untersuchten Projekte werden als Organisationen auf Zeit verstanden; alle Handlungen in diesen Projekten sind entweder genuin kommunikative Handlungen oder „von Kommunikation flankierte Handlungen, deren Kernursache oder Wirkungen Kommunikation sind“ [Mic05]. Um diese kommunikativen Handlungen in der Projektarbeit erfassen, einordnen und analysieren zu können, werden Leitdifferenzen entwickelt. Diese Leitdifferenzen ermöglichen die Beschreibung des Kommunikationsprozesses sowie die Verbindung von Prozess- mit Strukturmerkmalen. Jede Organisation – und damit auch jedes Projekt – entwickelt durch die für sie typischen Rahmenbedingungen und die daran anschließenden Kommunikationsprozesse ihre eigenen Kommunikationsmuster. Für die Untersuchung der Kommunikation in den Präventionsprojekten – insbesondere hinsichtlich der Beziehung zwischen Forschern und Praktikern – sollen Leitdifferenzen Instrumente zur Beschreibung der Kommunikation sein. Michulitz (2006) leitet aus unterschiedlichen Ansätzen der empirischen Forschung im Bereich der Organisationsentwicklung [Mül00, vR, FBF95] sechs Leitdifferenzen ab, die sie in Fallstudien zur internen Unternehmenskommunikation validiert: Kommunikationsorte, Kommunikationszeiten, Kommunikationswege, Personenkonstellation, Technische Hilfsmittel, Themen. In einer aktuellen Studie des Metaprojektes StArG wurden zur Untersuchung des Kommunikations- und Kooperationsverhaltens in den Forschungsprojekten des Förderschwerpunktes Präventiver Arbeits- und Gesundheitsschutz zentrale Projektakteure aus Forschung und Praxis in teilstandardisierten Interviews befragt. Im Rahmen einer rekonstruierenden Untersuchung [GL09] wurden aus den Aussagen der Interviewpartner Kriterien in Form von Variablen abgeleitet, die in ihren verschiedenen Ausprägungen die jeweilige Integration (Forschung in das Feld der Praxis sowie Praxis in das Feld der Forschung) durch kommunikative und kooperative Handlungen in einer Art zeitlichem Einschnitt des Kommunikationsprozesses im Forschungsprojekt beschreiben. Die Angaben der Interviewpartner wurden inhalts-analytisch ausgewertet und die jeweiligen Merkmalsausprägungen isoliert. Das entwickelte Kriteriensystem ermöglicht so eine qualitative Analyse des einzelnen Forschungsprojektes und zudem eine vergleichende Betrachtung zwischen den Projekten. Schließlich werden die aus der qualitativen Inhaltsanalyse stammenden Dimensionen zum Kooperations- und Kommunikationsverhalten in den jeweiligen Forschungsprojekten den sechs aus der Theorie abgeleiteten Leitdifferenzen zugeordnet (vgl. Tab. 1).

Tabelle 1 Leitdifferenzen nach Michulitz [Mic05] und zugeordnete Dimensionen zur Kommunikation und Kooperation in Projekten des Präventiven Arbeits- und Gesundheitsschutzes

Leitdifferenzen	Dimensionen und Ausprägungen der qualitativen Inhaltsanalyse (Auswahl)
Kommunikationsorte	Orte der Interaktion, gemeinsame Arbeitsräume, Rahmenbedingungen
Kommunikationszeiten	Dauer der Kooperation, Zusammenarbeit in Projektphasen, Kommunikationshäufigkeit, Nachhaltigkeit
Kommunikationswege	Entscheidungsfindung, Entscheidungsspielraum, Kommunikationsformen, Kommunikationsrichtung, Formalisierungsgrad, Feedbacksystem
Personenkonstellation	Akteursstruktur, Projektrollen, Rollenverständnis, Hauptzielgruppe, Beziehungsstruktur
Technische Hilfsmittel	Instrumente und Methoden zur gegenseitigen Integration

Ergänzt werden die Dimensionen der Befragung durch Ergebnisse von sogenannten Transfer-Diagnose Workshops. Ziel eines solchen Workshops ist neben der systematischen Analyse der Transfersituation die Sensibilisierung der Projektakteure für die verschiedenen Dimensionen und Charakteristika des Transferprozesses, der sich in der Zusammenarbeit in den jeweiligen Transferpartnerschaften zwischen Forschern, Praktikern und Intermediären vor dem jeweiligen Projekthintergrund realisiert [HLB10]. Neben der Erfassung der Zielgruppen des Präventionsvorhabens werden die spezifischen Rahmenbedingungen des Projektes hinsichtlich der Dimensionen Mensch, Organisation und Technik sowie deren triadischen Wechselwirkungen [Ayt] erarbeitet. Schließlich werden die Ziele und Inhalte des Präventionsprojektes gemäß den Rekursionsebenen Individuum, Organisation, Netzwerk und Gesellschaft erfasst. Dies eröffnet eine systematische Erfassung des Zielsystems und der inhaltlichen Ausrichtung des Projektes; diese Daten werden in einem zweiten Schritt in Bezug zu den adressierten Zielgruppen gesetzt. Es ist dabei zu prüfen, inwiefern die Inhalte und Ziele als eine von allen Projektakteuren gemeinsam getragene „Projektmission" verfolgt werden und inwiefern alle Interessensvertretungen zur Erzielung einer größtmöglichen Akzeptanz und nachhaltigen Umsetzung der Projektergebnisse in der Entwicklungsphase des Projektes integriert sind.

Die Analyse der Projekte mit Hilfe der vorgestellten Methoden hinsichtlich des Kooperations- und Kommunikationsverhaltens ermöglichen zum Einen als Diagnose- und Reflexionsinstrument eine systematische Spiegelung der „Transferarbeit" während der Projektlaufzeit. Zum Anderen wird durch die Zusammen- und Gegenüberstellung der unterschiedlichen Ansätze zum „Transfer" der analysierten Projekte des Förderschwerpunktes „Präventiver Arbeits- und Gesundheitsschutz" der „State of the Art" abgebildet. So lassen sich unterschiedliche Ansätze zur Gestaltung der Kooperation zwischen Forschern, Praktikern und Intermediären isolieren, die entsprechend dem Leitbild „Transfer Engineering" Kommunikation zwischen den Projektakteuren mit unterschiedlichen Instrumenten und Methoden entwickeln. Als gelungene Beispiele lassen sich u. a. die Projekt PräSend und PräTrans nennen. Das Projekt PräSend (Betriebliche Prävention durch Service Engineering und Dienstleistungsmanagement) verfolgt den in der Dienstleistungsforschung entwickelten Ansatz des Service Engineerings zur konsequenten Einbindung von Betrieben, Kammern und Verbänden in den Forschungsprozess erstmalig in der Präventionsforschung. In Transferpartnerschaften des Projektes PräTrans (Gesundheit Unternehmen) erarbeiten Forscher und Unternehmensvertreter und Intermediäre im Dialog bereits in der Konzeptentwicklung gemeinsam Maßnahmen und Lösungsräume für einen betrieblichen Arbeits- und Gesundheitsschutz.

5 Fazit

Verfahren und Ansätze zur Integration des Kunden in den Innovationsprozess sind in der Produktions- und teilweise in der Dienstleistungsentwicklung State-of-the-Art. Entsprechende Methoden für die Arbeitsforschung finden sich in Konzepten zur Partizipation und in der Aktionsforschung. Die Ergebnisse aus den vorgestellten Befragungen und Workshops mit den Projekten des Präventiven Arbeits- und Gesundheitsschutzes zeigen, dass diese Konzepte jedoch nicht konsequent umgesetzt werden. Forscher wie Praktiker beklagen ein Transferproblem, das sich u. a. in der mangelnden Umsetzung von Innovations- und Forschungswissen in (unternehmerischem) Handeln zeigt. Eine Lösung liegt in der Interaktionsarbeit der Projektakteure, die in der Zusammenarbeit gemeinsame Projektziele, Handlungsweisen und eine gemeinsame Sprache entwickeln. Transfer Engineering zielt auf die anwendungsorientierte Interpretation von Information, um so gemeinsames, neues Wissen zu schaffen. Es schlägt eine projektphasenübergreifende, bewusste Gestaltung der Kommunikations- und Kooperationsprozesse in Forschungsprojekten vor, in der die Rollen zwischen Experten und Laien, Forschern und Praktikern, Anbieter und Kunde verschwimmen. Die vorgestellten Leitdifferenzen mit den entsprechenden Dimensionen geben Anregungen zur Reflexion und Gestaltung von Kommunikations- und Kooperationsentwicklung in Forschungsprojekten.

Durch das „Leben" des Leitbildes Transfer Engineering realisiert sich das, was Volkholz als „Transferproduktivität" beschreibt; diese wird durch die „Lust, etwas zusammen zu tun, durch neue Formen praktischer Kreativitätserprobung, von Experimentieren" [mol07] erhöht. Gleichzeitig wird durch die konsequente und kontinuierliche Rückbindung der unterschiedlichen und sich ändernden Zielsysteme von Forschung, Unternehmen und weiteren Interessensvertretungen an den gemeinsamen Projektzielen die Kommunikation und damit die Kooperation im Forschungsprojekt entwickelt. Wenn dies gelingt, kann sich der Präventive Arbeits- und Gesundheitsschutz „daran messen lassen, ob er einen Beitrag zur Potentialentwicklung des Unternehmens leistet, zur Fähigkeit, sich auf Veränderungen einzustellen" (vgl. ebd.). Nicht Forschung isoliert kann ein Unternehmen wettbewerbsfähig machen; Forschung kann nur gemeinsam mit den Unternehmen und Intermediären die Potentiale der Arbeitsforschung und des Präventiven Arbeits- und Gesundheitsschutzes heben [HLBH09]. Bei dieser Art von Kooperation soll es nicht darum gehen, die Unterschiede zwischen Forschung und Praxis „zum Verschwinden zu bringen, sondern durch verstehens- und aushandlungsorientierte Prozesse aus- und abzugleichen, um gemeinsam getragene und tragfähige Entscheidungen zu finden" [HSS09]. Damit entwickelt sich das Paradigma der anwendungsorientierten Forschung vom „Forschen für die Praxis" zum „Forschen mit der Praxis"!

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A Joint Organizational and Technical Development of a Telematic Rescue Assistance System for German Emergency Medical Services

Marie-Thérèse Schneiders, Daniel Schilberg, Sabina Jeschke

Abstract The German research project Med-on-@ix aims at optimizing the efficiency and quality of preclinical emergency health care by introducing a Telematic Rescue Assistance Systems into the Emergency Medical Services. Paramedics and emergency physicians will be supported on site by a specialized physician in a remote Competence Centre. During the last three years, an interdisciplinary project team of emergency physicians, university scientists and developers supported by industrial enterprises developed a telematic system supporting the emergency care. The Telematic Rescue Assistance Systems provides the real time transmission of voice communication, vital parameters, pictures and videos from any emergency site using mobile radio networks. Both the technical development of the Telematic Rescue Assistance System and the organizational implementation into the regular operations of the Emergency Medical Services constitute the central pillars of the research project. Beside the technical requirements, the user centered requirement management applied within Med-on-@ix identified the necessary organizational changes to realize the introduction of the telematic system into Emergency Medical Services. This paper traces the joint organizational and technical development of the Telematic Rescue Assistance Systems based on a consistent user involvement into the development process. Simulation studies have been used to identify the main challenges regarding the implementation process. Exploring the impact of the system on the working process, organizational changes have been worked out, aiming at the design of a successful implementation process.

Key words: Telematic Rescue Assistance System, German Emergency Medical Services, Telemedicine, Joint Organizational and Technical Approach, Implementation Process

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1 Introduction

German Emergency Medical Services (EMS) professionals are supported in 50 % of all missions by a qualified emergency physician to guarantee the highest quality of care on emergency sites. These days, demographic development contributes amongst others to a considerable rise of missions involving EMS physicians [GHM03]. Whereas the demand of EMS has doubled since 1990, a serious lack of physicians particularly in rural areas can be considered. The closing of various EMS physician stations lead to a delayed arrival of the physicians on scene and thereby to an augmented interval without sufficient therapy. As paramedics and EMS physicians are organized in a so-called "rendez-vous system" [BHM08], physicians and paramedics arrive at the accident scene in different vehicles. The ambulance, staffed with paramedical professionals, reaches the patient in general within the statutory period of 12 minutes after the emergency call. Whereas mainly in rural areas the physicians gets delayed to the emergency patient, making it decisive to bridge the time period before the arrival of the emergency doctor [RMLK04].

To secure a high quality of treatment in the chain of survival [COT+91], innovative strategies to assure an early professional aide on scene are needed. As the German EMS is one of the highest qualified in the world, efforts are made to stick to the physician-led EMS in Germany by structural measures and hereby to provide the highest medical qualification to the patient. The expensive German emergency care gets a lot of stick these days, innovative solutions are needed to preserve the fundamental philosophy of bringing physician-centered definitive care to the patient, rather than bringing the patient to the care, as paramedic based EMS systems do.

The legislators have paved the way by assimilating rescue service acts, restructuring the rescue service catchment areas and the introduction of integrated demand-oriented control stations with a consequent quality management system as well as the implementation of a medical leader for each rescue department. Besides these improvements, the technological support of EMS offers a wide scope of possibilities to reduce the "no-therapy-time" by referring to communication technology that is used as self-evident in non-professional context.

The quality of EMS work is directly related to an efficient information management. As everyday experiences of EMS personnel are characterized by adverse surrounding conditions of work, it is furthermore affected by a constant lack of information regarding the specific emergency situation, the patient's history or his actual medication. The use of modern information technologies has the potential to intensify and to accelerate the information flow related to the actual mission.

So far research and development activities focus in particular the transmission of vital data from an ambulance to a hospital. The German project "Stroke Angel" [ZRM+08] transmits audio and video data from the ambulance in order to diagnose and pass on stroke patients directly to the nearest stroke unit. Using telemedicine the contact-to-balloon time decreased on average from 32 min to 16 min. Various similar publications testify that teleconsultation systems are considered potentially lifesaving [LHR+09]. The necessity to increase the mobility of

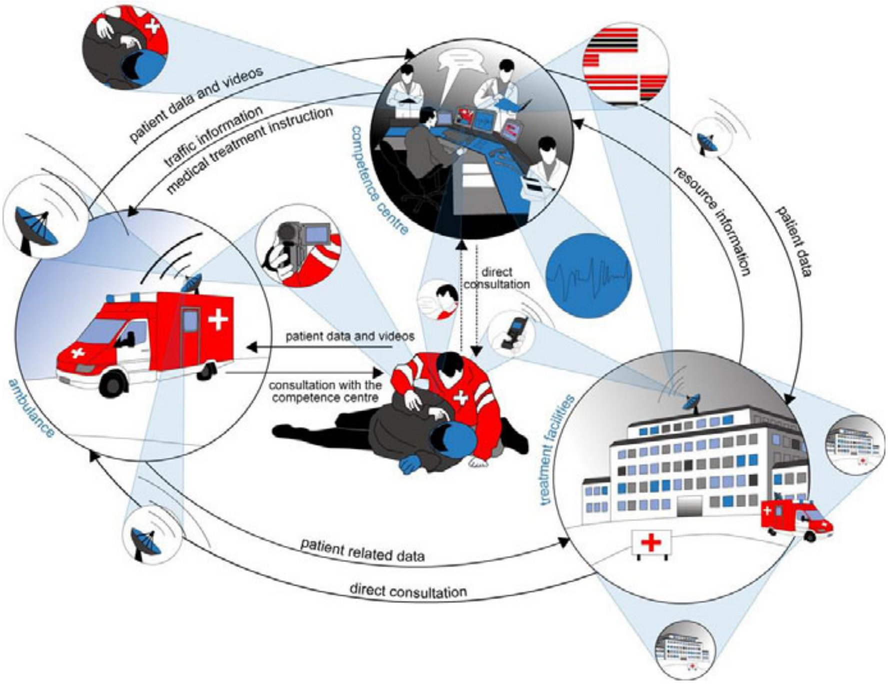

Fig. 1 The Telematic Rescue Assistance System

telemedical support systems for EMS operations is evident. Furthermore to avoid the development of isolated telemedical solutions and to foster the adoption into regular practice of EMS, integrated development and implementation approaches are needed.

Within the research project Med-on-@ix, the Telematic Rescue Assistance Systems (TRAS) offers the possibility to make medical know-how available at any time for professional helpers on scene. Medical and mission tactical data is transmitted via 3G mobile radio networks from the place of emergency or the ambulance vehicle to the remote emergency physician in the Competence Center (CompC), communicating with the staff at the place of emergency via audio connection. The CompC also helps to optimize workflows by arranging communication with the health care facilities to which patients subsequently will be sent [PGH09]. The technical components on site are connected to a communication which connects to the ambulance vehicle via an 802.11 network or directly to Public Switched Telephone Network (PSTN) and the Internet through GSM/TETRA and GPRS/UMTS. On the CompC's side the servers are connected to the PSTN via ISDN and to the Internet. The Clients in the CompC connect to the Servers through a reliable local network or VPN [PGH09].

The application scenario shown in Fig. 1 illustrates the central position took up by the remote EMS physician in the CompC.

The CompC serves as an information hub between the involved clinical and preclinical facilities. The use of the TRAS in the work of EMS is related to decisive changes in working processes. The remote emergency physician is confronted with an unknown job specification and a new working environment. The EMS team on site has to handle new medical equipment and modified team and communication processes.

By a constant participation of the University Hospital Aachen (UKA) in the requirement management process as well as the technical development and the implementation process, a one-year trial run could be realized (2009–2010). The trial run – as well as the preceding simulation studies – focused two possible scenarios involving on first level physicians and on second level paramedics on site being supported by the CompC. The elaboration of the organizational concept enabling the EMS to implement the system was designed in line with the requirement management used for the technical development.

This paper outlines the approach for a joint organizational and technical development of a TRAS referring to two simulation studies carried out within the last two years. Based on the example of the identified impact of the TRAS on communication processes on the emergency site, the change management approach is described. By the use of user group surveys, necessary changes and measures for a successful implementation into daily work of EMS were identified. Finally the described example will show the possibilities to face organizational and technical requirements regarding the operation of a TRAS.

2 Joint Organizational and Technical Development

The TRAS can be described as a sociotechnical system [PGH09] considering the relevant interactions between social, technical and organizational aspects in line with the development and the implementation of the system.

An iterative and incremental requirement management constitutes the core of the development process within Med-on-@ix. The agile development of the TRAS [Pro10] foresees the consequent involvement of the users at different stages of development. The applied research methods within Med-on-@ix meet this approach by considering aspects of human, organization and technology in every research question. The progressive specification of the TRAS is realized by the identification of the relevant functional and non-functional requirements within the scope of two experts workshop [PGH09] and two simulation studies.

The development process regarding both organizational and technical requirements is consequently attuned on the involvement of the different user groups (emergency physicians, paramedics), to increase system quality, user satisfaction and at least the usage of the TRAS. Both product requirements and functional specification have been elaborated in cooperation with the medical partners from UKA.

User involvement is referring to the participation of a representative group of potential users especially in two relevant areas: participative decision making and planned organizational change. The involvement of the target group contributes in both areas to higher motivation of users and the success of change processes [BO84].

In the Med-on-@ix project opinion surveys and interviews involving EMS professional have been used for example in line with the studies focused in this paper.

EMS teams and emergency physicians tested within different simulated rescue scenarios the telematic support system at different stages of development. Different social research methods were applied to survey 135 test persons (87 in the first study in 2008, 48 in the second study in 2009) in terms of acceptance and utilization issues [BO84]. The studies targeted on technical, as well as organizational and human research aspects. The test persons were trying out the main functions of the TRAS in simulated rescue scenarios, to test the handling of the technical system and to evaluate the impact on the working process. The developers gained awareness of usability aspects and susceptibilities of the system, whether the social scientists acquired knowledge about the impact of the TRAS on teamwork and communication processes.

Using replicated emergency situations as a testing environment the studies have specified and validated the implemented exigencies. The simulated test setting aimed at encouraging new behaviors dealing with the TRAS and at least to promote shared meanings about the system. Fostering the dialogue between developers and users especially in line with the requirement management has been contributing to a positive trend in terms of user acceptance of the TRAS [BO84]. The latter important results, described in related publications, reinforced the chosen research strategy of joint organizational and technical development combining user involvement and a holistic requirement management.

In addition, the present paper focuses the possibility using the described research approach to design a user oriented technology implementation process. The pursued change management approach based on transferring research results into change tasks will be described in the following by reference to the simulation studies.

3 Exemplified Change Management Approach in Med-on-@ix

The implementation of the TRAS into German EMS goes in line with the several changes regarding the working process in EMS Teams. To meet those challenges, the changing aspects have been identified at early stage in the development process in line with the incremental requirement management. The change tasks regarding in particular the organizational development of EMS have been detected for example in line with the conducted simulation studies. To illustrated the change management used in the Med-on-@ix project the concept and gained results of the simulation studies are exemplarily presented here.

Meeting the user centered research approach the studies encouraged paramedics and physicians to enter a dialog with developers and by there aimed at a system improvement through reflective practices using different methods of social sciences. Based on the results of those surveys the necessary changes were detected and transferred into change measures.

3.1 Simulation Studies

Within the scope of the simulation studies carried out at the Interdisciplinary Medical Simulation Center (AIXSIM) of the UKA, one main research question referred to the impact of the TRAS on the teamwork on site. The first survey in 2008 addressed the support of an emergency physician by another highly involved physician in two standardized simulated missions (ST-elevation myocardial infarction; severe traumatic brain injury). The second simulation study tackled the support of an EMS Team (two paramedics) by the remote emergency physician in the CompC. Five different scenarios (a diving accident, a renal colic, a second-degree burn, an intoxication and a hypoglycaemia) partly performed by patient-actors playing patients partly by involving a patient simulator offered the possibility to analyze the handling with and the potential of assistance of the TRAS.

To allow a comparison of the quality of treatment with and without the application of the TRAS, control groups acting without the telematic support were drafted in. Questionnaires and group interviews were used to survey the EMS Teams after the simulated operations. The issue-focused interview guide, applied within the semi-structured interviews, enabled the scientists to focus on behavior patterns observed before. The video-documented interviews were transcribed and put to a qualitatively oriented content analysis.

3.2 Results

Taking into account the results from both simulation studies, the impact of the TRAS on team internal processes turned out to be one of the main challenges within the organizational development of the system. The involvement of the remote physician created an unusual working environment, adding to the demanding emergency situation a new communicative arrangement and the use of supplementary equipment.

The communication structure during the operation is illustrated in the following Fig. 2: the standardized scenario foresees an EMS Team consisting of a physician and two paramedics respectively only two paramedics in the second study. As a new participant the remote emergency physician in the CompC is connected via mobil radio to all members of the team.

The first simulation study immediately revealed the main changes in the working situation. The test persons experienced an altered situation having a remote team member being involved into the scene. The interviews revealed a negative impact of the TRAS on the communication with the patient. The emergency physician was struggling to concentrate on both the communication with the remote colleague and with the aggrieved patient on site. The interviewed paramedics underlined furthermore the necessity to be connected to the CompC, to be able to follow the diagnoses and treatment discussion between the physicians. 83 % of the interviewees stated in 2008 a negative impact of the TRAS on the communication situation during the operation.

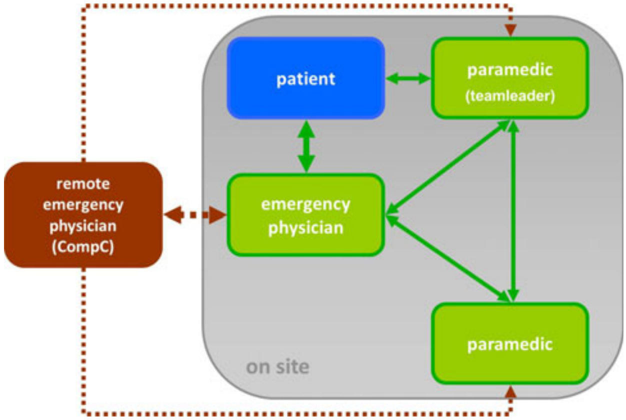

Fig. 2 Mission-related Communication Structure

Based on these results communication rules were elaborated and evaluated in the 2nd simulation study (2009) to prevent miscommunication, as the loss of information can be related to a safety hazard for the treatment of the patient. These rules compromise a clear role allocation between the team members assigning a standardized information committal between the physician (alternatively the team-leading paramedic) on site and the CompC after a first anamnesis. Furthermore the test persons in the second study were instructed in thinking loud, to reduce the necessity for the remote physician to ask question. The standardization of the working process on site using the ABCDE (Airway Breathing Circulation Disability Exposure) mnemonic, usually used for the prioritization in the management of trauma patients, also follows the aim of reducing the quantity of possible follow-up inquiries by the CompC.

The application of the elaborated communication rules clearly had a positive effect on the team communication in the 2nd study. Figure 3 indicates that over 50 % of the questioned test persons stated a positive or no impact of the TRAS on team communication, compared to 83 % complaining about negative impact in the first study.

Besides the importance of communication rules, the simulation studies uncovered the importance of mutual confidence between all members of the EMS team, including the remote EMS physician. The interviewees pointed out the importance of working on both sides, the CompC and on site, to acquire a team spirit that fosters the efficiency of teamwork, being exposed to stressful working conditions as in EMS missions.

Regarding the results of the studies three main challenges have been identified:

- The alternate communication structure needs to be supported by the use of communication rules.
- Both sides the CompC and the team on the emergences site have to follow standardized procedures to avoid miscommunication.

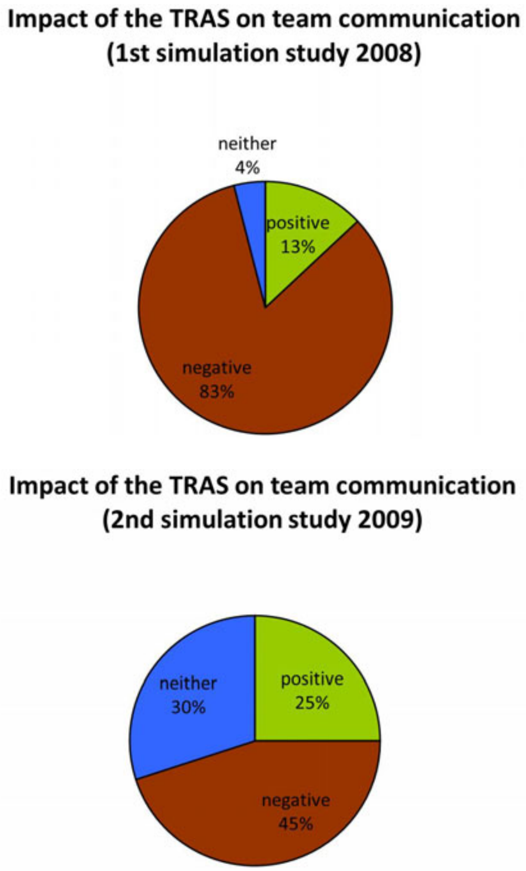

Fig. 3 Comparing results from simulation studies

- The success of the teamwork is mainly related to a sense of belonging between all involved team members.

To meet these requirements organizational changes have been designed and implemented to support a successful trail run.

3.3 Identification of Change Management Tasks

The selected results from the simulation studies were transferred into the change management concept, coming along with the implementation of the trial run in Aachen.

The standardized management of operations in the emergency department improves significantly the outcome of prehospital care [WBL+08]. The upcoming

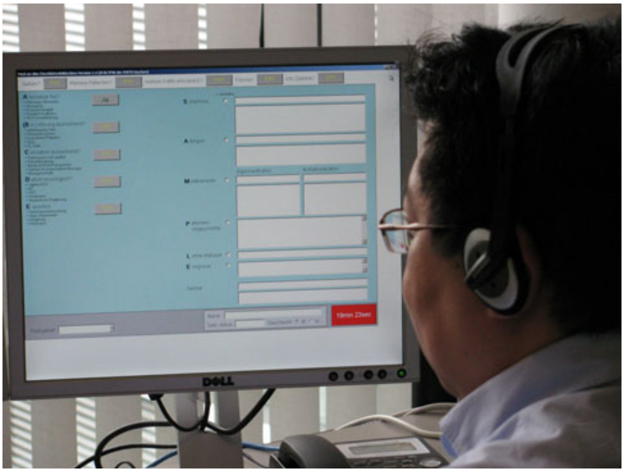

Fig. 4 ABCDE Checklist in the CompC

training concept of Prehospital Trauma Life Support® (PHTLS) teaches a standardized and established approach to the trauma patient in EMS operations [WBL+08]. This concept for prehospital management includes the ABCDE approach instructing EMS personnel to act according to the principle "treat first what kills first":

- **A**irway management, cervical spine stabilization
- **B**reathing (ventilation)
- **C**irculation (hemorrhage and perfusion)
- **D**isability
- **E**xposure/Environment.

By using these steps, the EMS personnel on site follow the standardized process, consisting in a primary survey focusing the vital functions of the patient, followed by a secondary survey to identify the relevant injuries. The application of this concept helps the remote physician to follow and to document the ongoing operation easily.

The achievement of a standardized working process using the ABCDE concept was supported by the implementation of a digital checklist (Fig. 4) in the CompC, supporting the physician in following step by step the work of his team on site.

The EMS personnel were trained on the use of the concept mainly on the job, supported by debriefings of the missions. Within the first phase of the trial run, the EMS teams got used to the standardized procedures.

The compliance of the defined working process was additionally fostered by the implementation of job rotation for the involved physicians between the CompC and the mission site. Furthermore the rotational assignment between the two positions counteracted the lack of mutual confidence required by the users. The experience of working together on site and knowing the working processes in the CompC encouraged the manageability of the TRAS.

To prepare the EMS personnel for the trial run of the TRAS, a specific training was inserted into the regular weekly classes at the fire department. Besides lessons on the content of the project, the regulatory framework of the trial run and the intensification of pharmaceutical knowhow, the formation comprised trainings on operational techniques like the initialization of intravenous accesses. In line with these courses the communication rules were integrated into a specialized lesson on communication in critical situations. The participants were put into the complex communication situation by different exercises, to be able to reflect the situation on site as well as the challenges, the remote physician is facing at. The lessons were used to discuss and first of all to further develop the rules of handling the TRAS. The training was consequently used to enhance the involvement of the user groups into the research project and hence to affect the user acceptance of the TRAS.

4 Conclusion and Outlook

The TRAS as a sociotechnical system compromises beside technological challenges particularly many organizational challenges, critical in view of a successful implementation of the TRAS into daily work of EMS. The development of such assistance systems therefor requires the involvement of all relevant stakeholders. The approach by a joint technical and organizational development has enabled the scientists to identify the necessary change management tasks. The latter were developed in cooperation with the user groups. The described results demonstrated the importance of user involvement right from the beginning of a development project. Various research results have shown so far “that user engagement during the installation phase is strongly associated with user satisfaction” [KM91]. The described research results underline the necessity of a development approach regarding both technical and organizational challenges enabling thereby an accepted implementation into the target organization.

The aim of Med-on-@ix is to support EMS in their daily work by using today’s technological innovations. To achieve an optimized work in emergency missions the user has to identify the requirements in terms of both types of requirements technical and organizational. Neglecting the latter is oftentimes the reason why innovative technological assistance is not turned into daily operation.

The final evaluation of the Med-on-@ix trial run by the end of 2010 will identify further change management tasks, which will support the implementation of the TRAS. To be able to run in a future scenario the telematic support of EMS paramedics throughout the “no-therapy-time”, the system will be further developed in a follow-up project already started in August 2010. The challenge of the latter will be the parallel implementation in five other regions around Aachen. The one-time approved change management approach developed within the Med-on-@ix project will be further developed in view of the design of an incremental implementation concept deserving at a time five emergency departments.

Due to the federal topology of the German EMS the user groups from different emergency department will differ particularly in qualification, but moreover in the handling of medical instruments or supporting systems. Therefore the organizational and technical requirements from the user groups have to be consistently refreshed and adopted to the specificities of the involved emergency department. This matter of fact reveals a further research subject: Besides the realization of a multi-case implementation the change tasks have to meet the individual requirements of the target departments.

The methodology of transferring the identified technical and organizational requirements into implementation measures of different types will be carried on in the coming month, on the one hand to develop an optimized change process but also to gain the necessary user acceptance by consequently involving the target user groups.

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Telenotarzt auf dem Prüfstand

Evaluation des Projekts Med-on-@ix aus Sicht der Rettungsassistenten

Marie-Thérèse Schneiders, Stephanie Herbst, Daniel Schilberg, Ingrid Isenhardt, Sabina Jeschke, Harold Fischermann, Sebastian Bergrath, Rolf Rossaint, Max Skorning

Zusammenfassung

Hintergrund. Die konsequente Nutzerorientierung in der Entwicklung des Telemedizinischen Rettungsassistenzsystems (TRAS) ist zentrale Strategie des Projekts Med-on-@ix. Zur optimalen Einpassung des Systems in die Arbeitsabläufe des Rettungsdienstes erfolgte in allen Projektphasen ein konsequenter Dialog mit den Nutzergruppen. Diese Studie befasst sich mit der Evaluation des Systems durch die Aachener Rettungsassistenten im Anschluss an eine 10-monatige Praxisphase.

Material und Methoden. Ein Fragebogen aus insgesamt 14 offenen und geschlossenen Fragen diente der Identifikation positiver und negativer Auswirkungen der Systemeinführung aus Sicht der Rettungsassistenten. Anschließend wurden in einer 45-minütigen Gruppendiskussion Fragen von Seiten der Rettungsdienstmitarbeiter geklärt und Feedback an die Systementwickler eingeholt.

Ergebnisse. 83,9 % der Befragten hielten den Einsatz eines Telenotarztes generell für sinnvoll. Positiv hervorgehoben wurden insbesondere die Verbesserung der fachlichen Unterstützung bei kritischen Entscheidungen, eine leitlinienkonformere Versorgung, die Erhöhung der Diagnosesicherheit sowie der schnellere Datenaustausch und -zugriff durch das TRAS. Optimierungsmöglichkeiten wurden bezüglich der Ausgestaltung des technischen Systems sowie der Kommunikationsabläufe im Einsatz identifiziert.

Schlussfolgerung. Das Potential des TRAS wurde von den Rettungsassistenten bestätigt. Der Einsatz des Telenotarztes kann aus Sicht der Befragten Qualität und Effizienz der Notfallversorgung steigern. Der Verbesserungsbedarf (Miniaturisierung der Technik und Intensivierung der Schulungsmaßnahmen) muss im Nachfolgeprojekt „TemRas – Telemedizinisches Rettungsassistenzsystem“ fokussiert werden.

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Schlüsselwörter: Telekonsultation, Rettungsdienst, Telemedizinisches Rettungsassistenzsystem, Akzeptanzforschung, Nutzerorientierte Entwicklung

1 Einleitung

Im Dezember 2009 wurde die Einführung eines Telemedizinischen Rettungsassistenzsystems (TRAS) auf einem Aachener Notarztwagen (NAW) realisiert. Während viele technologische Entwicklungen den Sprung in den Regelbetrieb aufgrund mangelnder Praxisorientierung verpassen, setzten die Mitarbeiter des Projekts Med-on-@ix (2007-2010) zur Gewährleistung einer möglichst optimalen Einpassung des Systems in die Arbeitsabläufe des Rettungsdienstes auf eine konsequente Nutzerorientierung in der Entwicklung. Wenige Wochen nach Abschluss von über 450 Einsätzen bewerteten die Rettungsassistenten, die in die Erprobung eingebunden waren, das TRAS.

2 Hintergrund

Ziel des Forschungs- und Entwicklungsprojektes Med-on-@ix, das von 2007 bis 2010 vom Bundeswirtschaftsministerium (BMWi) im Förderprogramm SimoBIT (www.simobit.de) [SBR+09a] gefördert wurde, ist die Qualitäts- und Effizienzsteigerung der Notfallversorgung durch den Einsatz von Telekonsultation. Zentrale Idee ist das Etablieren eines ständig verfügbaren Telenotarztes zur Unterstützung von Notärzten und Rettungskräften im Einsatz – insbesondere in kritischen Situationen. Des Weiteren kann das Rettungsdienstpersonal durch die Bereitstellung und Weitergabe therapierelevanter Informationen, z. B. an die weiterbehandelnde Klinik, in seiner Arbeit entlastet werden und die Zeit bis zur definitiven Behandlung im Krankenhaus verkürzt werden.

Eine Echtzeitdatenübertragung vom Einsatzort zur Telenotarztzentrale ermöglicht dem Telenotarzt, den gesamten Einsatz zu verfolgen. Die sofortige Live-Übertragung von Vitalparametern und Bildmaterial von der Einsatzstelle sowie die konstante Sprechverbindung mit dem Rettungsteam bilden die Grundlage für eine medizinische und einsatztaktische Unterstützung durch den Telenotarzt. Die Erhebung der Vitaldaten erfolgt über einen mobilen Intensivmonitor. Zusätzlich wird eine Fotokamera mitgeführt. Ein Video-Livestream wird dem Telenotarzt aus dem Rettungswagen bereitgestellt.

Die sichere und zuverlässige Datenübertragung wird über 3G-Mobilfunkverbindungen realisiert, indem eine eigens entwickelte Kommunikationseinheit (siehe Abb. 1, 2 und 3) 4 Mobilfunkverbindungen verschiedener Anbieter bündelt und den notwendigen medizintechnischen Komponenten und Applikationen ein lokales Netzwerk zur Verfügung stellt [PGH09]. Die Kommunikationseinheit wird als zusätzliches Equipment mitgeführt und ermöglicht mit Einsatzbeginn eine automatisierte Einleitung der Datenübertragung.

Abb. 1 Die Kommunikationseinheit ist in einen Rucksack integriert und ermöglicht eine sichere und zuverlässige Datenübertragung vom Einsatzort an die Telenotarzt-Zentrale

Abb. 2 Kommunikationseinheit aus Abb. 1

Abb. 3 Zur Erprobung des Telemedizinischen Rettungsassistenzsystems wurde ein Rettungswagen der Berufsfeuerwehr Aachen telemedizinisch umgerüstet

Die organisatorische Umsetzung stellte neben der technischen Entwicklung eine zweite Säule des Vorhabens dar. Eine Anpassung des Systems an die Herausforderungen im Rettungsdienst erfolgte durch den konsequenten Dialog mit den Nutzergruppen, sodass in unterschiedlichen Projektphasen das Feedback von Notärzten und Rettungsassistenten für eine nutzerorientierte Systemgestaltung eingeholt wurde – beispielsweise im Rahmen von Simulationsstudien [SBR+09b].

Die Untersuchung der technischen und organisatorischen Einsatztauglichkeit sowie die Analyse der medizinischen Nutzbarkeit und der Auswirkungen des Systems erfolgten von November 2009 bis September 2010 im Regelbetrieb des Aachener Rettungsdienstes. Im Anschluss an diese Evaluation wurden im November 2010 die Aachener Rettungsassistenten zu ihren Erfahrungen befragt.

3 Ablauf der Befragung/Methode

Für den Evaluationsbetrieb wurde ein Rettungswagen der Berufsfeuerwehr Aachen telemedizinisch aufgerüstet und, mit einem zusätzlichen Notarzt besetzt, im regulären Betrieb des Rettungsdienstes als NAW disponiert. Die primäre Anwendung des Systems erfolgte durch den vor Ort anwesenden Notarzt. Die Konsultation fand in der Regel initial zwischen Telenotarzt und Notarzt vor Ort statt.

Auch die Rettungsassistenten verfügten über Headsets, damit das Gespräch zwischen Notarzt und Telenotarzt verfolgt werden konnte. Durch Knopfdruck war auch ein Wechsel der Sprecherrolle möglich. Die Rettungsassistenten wurden im Rahmen des täglichen Wachunterrichts auf den telemedizinisch unterstützten Einsatz vorbereitet, indem der Umgang mit den medizintechnischen Komponenten trainiert und organisatorische, rechtliche, medizinische sowie wissenschaftliche Rahmenbedingungen vermittelt und diskutiert wurden. Die Rettungsassistenten wurden je nach Verfügbarkeit und Dienstplan auf dem NAW eingesetzt, es fand keine gezielte Personalauswahl statt. Im Durchschnitt rückte der NAW zu etwa 4 Einsätzen pro Tag aus, insgesamt wurden über 450 Patienten behandelt.

Im Rahmen einer Weiterbildungsmaßnahme der Berufsfeuerwehr Aachen im November 2010 wurden 58 Rettungsassistenten und eine Rettungsassistentin von den Projektmitarbeitern des Lehrstuhls für Informationsmanagement im Maschinenbau (IMA) der RWTH Aachen University und der Klinik für Anästhesiologie des Universitätsklinikums Aachen zu ihren Erfahrungen mit dem System befragt. Die Teilnehmer waren im Alter zwischen 24 und 49 Jahren, im Durchschnitt seit 10 Jahren im Rettungsdienst tätig und sowohl Rettungsassistenten als auch feuerwehrtechnisch ausgebildet. Sie waren unterschiedlich intensiv in die Entwicklung des Systems involviert und lernten es zu verschiedenen Zeitpunkten bzw. in unterschiedlichen Entwicklungsstadien kennen.

Die Befragung umfasste einen Fragebogen mit insgesamt 14 offenen und geschlossenen Fragen, wobei die Antwortmöglichkeiten der geschlossenen Fragen unter Verwendung einer Likert-Skala [SHE99] in 6 Dimensionen unterteilt wurden. Die positiven und negativen Auswirkungen der Systemeinführung sollten eingeschätzt und die Erfahrungen mit dem Einsatz des Systems dargelegt werden. Anschließend erfolgte eine offene 30- bis 45-minütige Gruppendiskussion. In einer früheren Projektphase wurden im Rahmen von Nutzerbefragungen Chancen und Risiken des Einsatzes des TRAS identifiziert und im Kontext projektbegleitender Evaluationen diskutiert. Die Fragestellungen wurden durch im Projekt tätige Notfallmediziner und Sozialwissenschaftler entwickelt und einem internen Pretest unterzogen.

Während die Notärzte und Telenotärzte, die das System im Einsatz testeten, als Projektmitarbeiter im ständigen Dialog mit den Entwicklern standen, wurde das Feedback der Rettungsassistenten als weitere – jedoch nicht befangene – Nutzergruppe mit Hilfe einer teilstandardisierten Befragung eingeholt.

4 Ergebnisse

51,7 % der Befragten bestritten mindestens 10 Einsätze mit dem Telenotarzt. 14 Personen (23,7 %) nahmen 2008 und/oder 2009 bereits an Simulationsstudien des Projekts Med-on-@ix teil und konnten in diesem Rahmen einzelne Systemfunktionalitäten in der Anwendung testen und bewerten.

4.1 Verbesserungen durch den Einsatz des Telenotarztes

83,9 % der Befragten bejahten die Frage „Halten Sie den Einsatz eines Telenotarztes im Rettungsdienst generell für sinnvoll?“ In Abb. 4 sind die von den Rettungs-

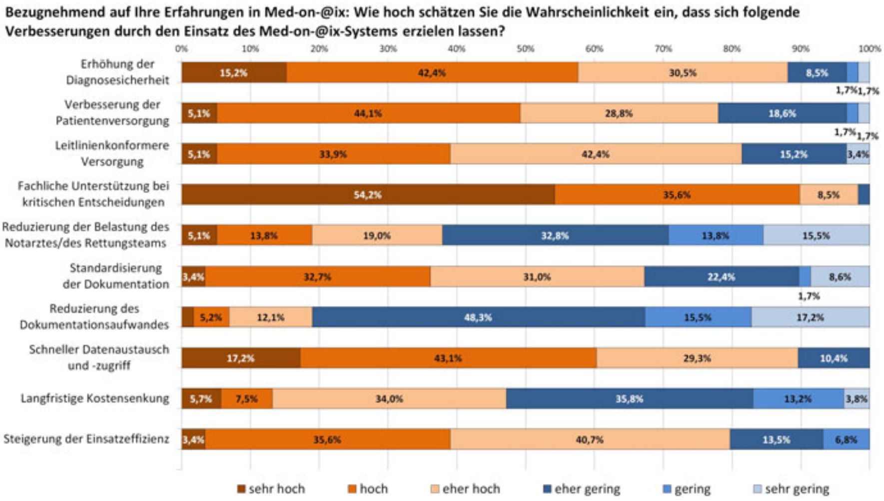

Abb. 4 Chancen des Telemedizinischen Rettungsassistenzsystems im Vergleich

assistenten erwarteten Verbesserungen durch den Einsatz des Telenotarztes aufgeführt. 89,9 % der Befragten schätzten den positiven Einfluss des Systems auf den Aspekt *fachliche Unterstützung bei kritischen Entscheidungen* als hoch oder sehr hoch ein. Auch eine *Erhöhung der Diagnosesicherheit*, eine *Verbesserung der Patientenversorgung* sowie eine *leitlinienkonformere Versorgung* wurden als positive Effekte erwartet. Die Wahrscheinlichkeit eines schnellen *Datenaustauschs und -zugriffs* schätzten aufsummiert 89,6 % der Befragten eher hoch bis sehr hoch ein. Indifferent zeigten sich die Befragten bezüglich einer *langfristigen Kostensenkung* durch den Systemeinsatz. Eher gering wurde die Auswirkung des TRAS auf die *Reduzierung der Belastung des Notarztes/des Rettungsteams* und die *Reduzierung des Dokumentationsaufwands* eingeschätzt (siehe Abb. 4).

Im offenen Teil des Fragebogens gaben die Rettungsassistenten an, dass sich „ein Plus-Gefühl an Sicherheit durch eine 2. Meinung" einstellte sowie eine „schnelle Abklärung von Krankheitsbildern" möglich wurde. Besonders in kritischen Situationen bedeute die Meinung des Telenotarztes eine rechtliche Absicherung der Rettungsdienstmitarbeiter. Die Befragten sagten des Weiteren aus, dass die optimierte Informationslage über den Patienten und die Möglichkeit, z. B. „schnelle Informationen bei unbekannten Medikamenten" während des Einsatzes zu beschaffen, zu einer „zielgerichteten Handlung durch Background-Info" beitrugen. Die Rettungsassistenten berichteten von positiven Erlebnissen mit der Voranmeldung durch den TNA in der Zielklinik: „keine bzw. geringe Wartezeiten" und „gute Vorbereitung der Pflegekräfte und der Ärzte". In der Gruppendiskussion wurde herausgestellt, dass der Telenotarzt Entscheidungshilfen biete und eine Unterstützung bei der Auswahl und Voranmeldung in der Klinik darstelle. Dies ermögliche eine Zeitersparnis.

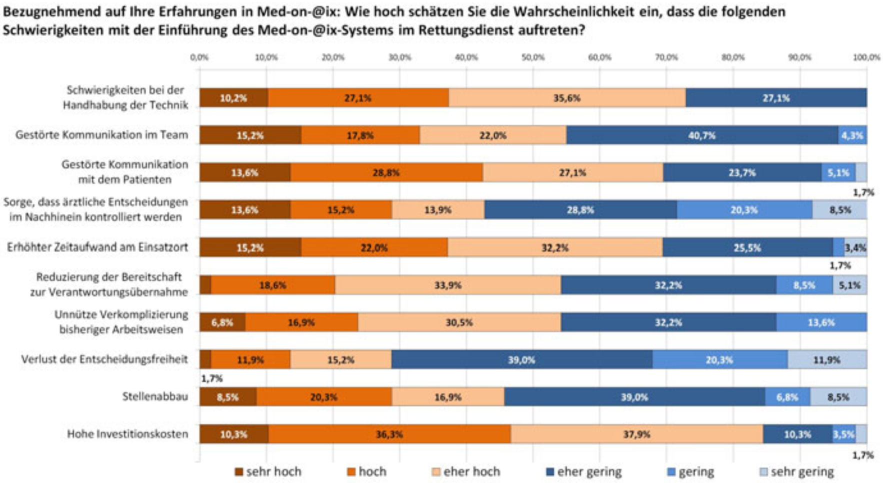

Abb. 5 Risiken des Telemedizinischen Rettungsassistenzsystems im Vergleich

4.2 Schwierigkeiten durch den Einsatz des Telenotarztes

In Abb. 5 werden die von den Rettungsassistenten erwarteten Schwierigkeiten und Risiken bezüglich einer Systemeinführung dargestellt. Den Aspekt *Handhabung der Technik* bewerteten in Summe 72,9 % der Befragten mit sehr hoch, hoch oder eher hoch. Weiterhin stellten die Befragten in der Evaluation heraus, dass sie einen *erhöhten Zeitaufwand am Einsatzort* in Kauf nehmen mussten. Ein *Verlust der Entscheidungsfreiheit* durch den Einsatz eines Telenotarztes wurde von einer Minderheit der Befragten erwartet. Die Items *Reduzierung der Bereitschaft zur Verantwortungsübernahme, Unnütze Verkomplizierung bisheriger Arbeitsweisen* und *Stellenabbau* zeigen eine große Streuung der Antworten.

Im offenen Teil des Fragebogens und in der Gruppendiskussion wurde von Schwierigkeiten, wie z. B. „Irritationen des Patienten durch Kommunikation mit dem Telenotarzt", berichtet, die nach Meinung der Befragten verunsichernd auf das Team und den Patienten wirkten. Für einige der Befragten resultierte dies aus der Fokussierung auf die technische Erprobung: „Leider stand bei den von mir erlebten Einsätzen die Technik und die Kommunikation mit dem Telenotarzt im Vordergrund." Außerdem seien Patienten im Vorfeld des Einsatzes nicht immer über das Projekt informiert gewesen und die andersartige Behandlungssituation habe ältere Patienten teilweise überfordert.

Der Umgang mit dem neuartigen System und „technische Probleme" provozierten aus Sicht der Rettungsassistenten einen erhöhten Zeitaufwand: „Wir waren sehr beschäftigt mit der Technik, möglicherweise, weil es noch nicht in Fleisch und Blut übergegangen ist." Dies gelte insbesondere für die Zeitspanne nach dem Eintreffen am Einsatzort. Die Befragten berichteten außerdem von für sie teilweise nicht eindeutigen Rollenverteilungen zwischen Telenotarzt und Notarzt.

Aspekte wie hohe Investitionskosten oder auch das Risiko eines nachgelagerten Stellenabbaus durch die Einführung des Systems wurden in der Gruppendiskussion durch die Befragten nicht aufgegriffen.

5 Diskussion

Die Bewertung durch die Aachener Rettungsassistenten beschloss die Serie projektbegleitender Erhebungen des Nutzerfeedbacks. Viele Herausforderungen der Entwicklung und Einführung eines derart komplexen Systems zeigen sich für die Entwickler und die Nutzer erst in der täglichen Anwendung. Die kritische Reflexion der Erfahrungen, die mit dem System gesammelt wurden, war für das Entwicklerteam dementsprechend ein wichtiger Meilenstein für zukünftige Optimierungsmaßnahmen.

Die Kombination einer anonymisierten schriftlichen und einer Befragung in der Gruppe erfolgte, um sowohl individuelle Meinungen als auch Tendenzen der gesamten Gruppe abzubilden. Während der Fragebogen eine standardisierte Abfrage der Einstellungen Einzelner darstellt, bietet die Gruppendiskussion Freiräume für kritische Anmerkungen und kreative Ideen, die im Fragebogen nicht berücksichtigt werden konnten [BD05].

Aufgrund der im Vergleich zu Abb. 4 höheren Streuung der Antworten in Abb. 5 sind wenige Items als eindeutig von den Rettungsassistenten erwartete Schwierigkeiten einzustufen. Da die Frage „Halten Sie den Einsatz eines Telenotarztes im Rettungsdienst generell für sinnvoll?“ von einem Großteil der Befragten (83,9 %) bejaht wurde, scheint die Probandengruppe der telemedizinischen Unterstützung trotz zahlreicher kritischer Rückmeldungen Potential anzuerkennen. Auch die überwiegend konstruktive Formulierung der jeweiligen Kritiken weisen in diese Richtung.

Da u. a. die Beteiligung der Befragten am Entwicklungsprozess stark variierte, ist davon auszugehen, dass die Interviewgruppe dem Vorhaben gegenüber sehr heterogen eingestellt war. Dies insbesondere, da im Kontext weiterer Erhebungen innerhalb des Projekts bereits beobachtet werden konnte, dass die Akzeptanz [Qui06] bei den Nutzern v. a. durch die Partizipation am Entwicklungsprozess beeinflusst werden kann [SPI09].

Die Ergebnisse zeigen eindeutige Hinweise auf den zukünftigen Einsatz des Systems. So wurde der verbesserte Informationsfluss zwischen Leitstelle, Rettungsdienstpersonal und Zielklinik als entscheidend herausgestellt. In der Bereitstellung und zielgerichteten Weitergabe therapierelevanter Informationen besteht nach Meinung der Befragten das größte Potenzial. Die Möglichkeit, ärztliches Know-how besonders in kritischen Entscheidungssituationen per Telekonsultation bereitzustellen, wird von den Rettungsassistenten als „doppelter Boden“ bzw. „Rückendeckung“ wahrgenommen. Erhöhung *der Diagnosesicherheit, Verbesserung der Patientenversorgung sowie leitlinienkonformere Versorgung* wurden als positive Effekte des TRAS bestätigt.

Im Vermeiden unnötiger Transporte in die Klinik liegt ein weiteres Potenzial der telemedizinischen Konsultation. Die Möglichkeit, bei einem qualifizierten Notfallmediziner eine zweite Meinung einzuholen, steigert nach Meinung der Befragten die Qualität der Patientenversorgung. Die Effizienzsteigerung durch den Einsatz der Telemedizin äußert sich für die Rettungsassistenten besonders in der optimierten Patientenübergabe. Die Übermittlung der notwendigen Informationen zu Patient, Verdachtsdiagnose und präklinischer Therapie an den aufnehmenden Arzt bedeutet für die Rettungsassistenten eine Entlastung. Darüber hinaus liefert der Telenotarzt die notwendige Rechtssicherheit im Einsatz.

In der geschlossenen Befragung wurde dem System ein eher erhöhter Zeitaufwand beigemessen, der z. T. auf mangelndes Training zurückgeführt wurde. Die Ergebnisse der Gruppendiskussion verdeutlichen jedoch gleichzeitig, dass die sofort verfügbare ärztliche Kompetenz des Telenotarztes die Notfallversorgung aus Sicht der Befragten insgesamt erheblich beschleunigt. Es ist daher davon auszugehen, dass dieses Potenzial bei routiniertem Umgang mit dem System weiter ausgeschöpft werden kann.

Auch wenn die abgefragten Aspekte nicht gewichtet wurden, gibt die häufige Thematisierung einiger Schwerpunktthemen im Rahmen der Gruppendiskussionen Hinweise auf die Relevanz der einzelnen Themen. So erscheinen aus Sicht der Befragten das Zeitmanagement und die Kommunikationsabläufe, die durch den Technikeinsatz direkt beeinflusst werden können, besonders bedeutsam. Der Stellenwert dieser Aspekte ist auch in Zusammenhang mit der Behandlungsqualität hervorzuheben. Der unmittelbare Bezug zur Anwendung des Systems im Einsatz ist hingegen bei Themen wie Investitionskosten oder Personalabbau nicht gegeben.

Insbesondere zu Technik und Kommunikation wurde deshalb Optimierungsbedarf identifiziert. Die Miniaturisierung der Kommunikationseinheit und die weitere Steigerung der Zuverlässigkeit müssen im Rahmen der folgenden Entwicklungen fokussiert werden – nicht zuletzt, um die Akzeptanz des Systems weiter zu erhöhen. Das Risiko einer gestörten Kommunikation innerhalb des Rettungsteams – und damit einer verminderten Qualität der Kommunikation mit dem Patienten – wurde bereits in den Simulationsstudien identifiziert [SPI09]. Die infolgedessen ergriffenen Schulungsmaßnahmen zum Training der veränderten Kommunikationsabläufe müssen angesichts der Evaluation optimiert werden. Rettungsassistenten, Notärzte und Telenotärzte müssen sich mit ihren Rollen intensiver vertraut machen und ihr Einsatzverhalten besser aufeinander abstimmen. Insbesondere der Telenotarzt muss aufgrund seiner beratenden Rolle dafür Sorge tragen, dass die Arbeitsabläufe durch den Konsultationsprozess nicht gestört werden, und auch vor Ort muss eine klare Aufgabenverteilung erfolgen.

5.1 Limitationen der Studie

Die unterschiedlich starke Einbindung in den Evaluationsbetrieb und die mögliche Herausbildung und Fokussierung der Meinung Einzelner im Rahmen der Gruppendiskussionen limitieren die generelle Übertragbarkeit der Ergebnisse.

5.2 Fazit für die Praxis

Die nachhaltige Etablierung von Telemedizin im Rettungsdienst hängt insbesondere von der Akzeptanz der Nutzer sowie einer problem- und kontextgerechten Systemgestaltung ab. Damit das telemedizinische System nicht als Insellösung endet, ist eine nutzergerechte Gestaltung der Technik und der notwendigen organisatorischen Maßnahmen entscheidend. Das Med-on-@ix-Projektkonsortium wird sich daher im Nachfolgeprojekt „TemRas – Telemedizinisches Rettungsassistenzsystem", das vom Innovationsministerium NRW (2010–2013) gefördert wird, den Herausforderungen stellen, dieses System weiterzuentwickeln und mit der Ausweitung auf 5 Rettungsdienstbereiche einen breitenwirksamen Einsatz des Systems zu realisieren. Die hier vorgestellten Studienergebnisse bilden eine wichtige Basis für dieses Vorhaben. Die Miniaturisierung der Technik sowie die Erarbeitung eines optimierten Schulungskonzepts mit konsequenter Ausrichtung an den Bedürfnissen des Rettungsdienstes sind zentrale Strategien des Projekts TemRas.

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Discussions on Accessibility in Industrial Automation Systems

Helmut Vieritz, Farzan Yazdi, Nasser Jazdi, Daniel Schilberg, Sabina Jeschke, Peter Göhner

Abstract Importance of industrial automation systems, also known as technical devices, has been a growing area during the past decades. Web applications from one side and industrial automation systems from the other side have become a standard part of people's daily life and more user groups have to deal with them. Hence they must be accessible to all users. Unfortunately, often by the development of such systems, certain user groups are being neglected. Therefore, a systematic concept is required to support the development of industrial automation systems and Web applications. In this paper, we will present the concept, which is proposed in the context of a research project funded by Deutsche Forschungsgemeinschaft (DFG). We will discuss the suited methods to effectively assess accessibility requirements.

Key words: Accessibility, User Interface, Industrial Automation System, Model-Driven Engineering

1 Introduction

Pervasive computing as a growing phenomenon has attracted many companies and manufacturers. Progressively more industrial automation systems are becoming a typical part of people's daily life. On the other hand, assessing accessibility to industrial automation systems is an essential requirement, if they are to be used by all members of the society. While accessibility has been more considered in Web applications, industrial automation systems have been less considered in this respect. Nowadays in many cases, Web applications are being combined into indus-

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trial automation systems. Many Web-based technologies such as HTML or XML are so common that are often being adopted for industrial automation systems; e.g. for presentation of the user interfaces (UIs) or in Automotive Open System Architecture (AUTOSAR). Clearly, all users should have free access to the industrial automation systems, including those with disabilities. Unfortunately, often certain user groups are being neglected by the development. The needs of users vary strongly, depending on their capabilities and expectations etc. This causes the development process very complex. Therefore, integration of accessibility requirements into the development process is cumber-some. User-centered Design (UCD) [iso] is strongly recommended for integrating none-functional require-ments, in our case accessibility [Hen07], into the development process, since none-functional requirements can strongly affect the system architecture [CWK05]. Hence, it is reasonable to consider them early enough before the architecture has been designed. The integration of UCD in Model-driven Engineering (MDE) provides a formalized development process. For better understanding, we will explain the proposed concept with an example. Our example is imaginary and should only serve as a support throughout this paper. Furthermore, with this example, we can better show the application of the concept in real life. Our example considers shopping in a futuristic supermarket by visually impaired customers. Typically, supermarkets are not accessible for visually impaired customers without the support of another person. Non-visual guidance to particular departments and items is missing. Apart from degradation of the quality of life for visually impaired customers, extra personal effort is required for helping such customers around. These aspects are investigated in a project running between RWTH Aachen University and University of Stuttgart. The example considers a supermarket with various items available for the customers to buy and the consulting service in the context of a supermarket. Considering these two factors in the context of shopping, the accessibility (see section Accessibility) of a pervasive system refers to free access to the products and services (considering its intended usage), for all users including those with disabilities; i.e. all customers should be able to access info materials or products in the supermarket and obtain the offered services. The proposed concept is UCD-based. Moreover, it relies on MDE approaches. For more simplicity, we have limited ourselves to the UI of an intelligent system that helps guiding the visually impaired customers throughout the supermarket and provide him with his/her required information. In this article, first we address basics of accessibility and UCD, which are the basics for our concept. Further-more, we will demonstrate our conception using an example. In the final section, we will provide a conclusion and outlook in the field of accessibility development of industrial automation systems.

2 Related Research

Along with MDE instructions and for the purpose of integrating accessibility into the UI, the UI must be modeled. However, modeling UI with conventional methods, e.g. UML is not possible. The existing approaches for modeling UI can be grouped into two categories: 1) practical approaches, e.g. User Interface Markup Language (UIML), User Interface Description Language (UIDL), or Extensible Application Markup Language (XAML) and 2) analytical approaches, e.g. User Interface Extensible Markup Language (UsiXML) or the Unified Modeling Language for Interactive Applications (UMLi). Practical approaches are focused on a usable platform-independent development of UIs including development tools. Recent implementations such as Silverlight or Flex provide the separation of UI layout from UI behavior as well as from system core functionalities. Whereas analytical approaches are more abstract and includes a meta model for all UI aspects, which describes UI structure, components, behavior, navigation, domain, and resource. However, the analytical approaches are still under research and there is lack of tools for actual development. The existing analytical approaches for the modeling of UIs, e.g. useML [Reu03], UMLi, Task Modeling Language (TaskML) and Dialog Modeling Language (DiaMODL) integrate the requirements of the modeling process including analysis. Nevertheless, rarely modeling solutions address complete and systematic integration of accessibility in model-driven design and more importantly in the development process [YHGS04, GKJ$^+$08, JPV08].

3 Basics

3.1 Accessibility

Accessibility in UI design means free perception and control of all relevant information for all users, also for those with disabilities. Here, the information refers to those being needed by the user to follow his intended workflow constituted by his activities, actions and their relationships. Industrial automation systems increasingly contain more functionality; hence, they are getting more complex in usage. Often not all functionalities are needed by all users (or even should not be accessible) or some of the users are being neglected in the development, e.g. modern cell phones are mostly inappropriate for elderly. To overcome these issues, UCD is often claimed to better meet the requirements of usability and accessibility [Hen07]. The existing accessibility solutions are focused on accessibility guidelines, e.g. on the Web Content Accessibility Guidelines (WCAG) [W3C08]. Unfortunately, they mostly aim at run-time behavior of the system, i.e. how the system should work but not how it should be developed. Moreover, they are specifically created for Web applications. Whereas, industrial automation systems have similar accessibility requirements as Web applications, as long as human interaction with UI is concerned. Fortunately, the guidelines can be adopted for industrial automation systems and UCD is a promising approach for the UI development of industrial automation systems. Despite the importance of accessibility, it is still a big challenge integrating it to the industrial automation systems, due to numerous reasons. Few important features are:

- Variety of the requirements of different user groups
- Lack of a systematic UCD-based development process
- Limiting UI technologies e.g. cell phones with small GUIs
- Difference between developer's mindset with that of the user.

Guidelines issuing accessibility for UI, such as the WCAG of the World Wide Web Consortium (W3C), describe requirements of accessible Web content. They are combined with other recommendations for user agents, authoring tools and Rich Internet Applications (RIA) [W3C09]. Although they are initially intended for Web applications, there have been successful attempts in adopting these guidelines for industrial automation systems. An example for such accessibility guidelines, which has been adopted from Web accessibility guidelines, is W3C extension of the WCAG to fulfill the requirements of the elderly using cell phones. The success in such attempt lies in the fact that many requirements are equal or similar in both systems. Moreover, as mentioned earlier, industrial automation systems and Web applications are being often combined together. Further examples of accessibility guidelines are guidelines from IBM or Microsoft for desktop applications.

3.2 User-Centered Design

User-centered design is another important study field, which crosses accessibility in many respects. It is a development philosophy, which tries to integrate the end users into the development process. User requirements are integrated in the early stages of the development process. As mentioned in the introduction, accessibility can strongly impact system architecture; thus early considerations can avoid late changes and additional costs. Roughly speaking, system design, definition of functionalities and UI design are parallelized in UCD. Using an appropriate architecture pattern supports this synchronization. The basic idea is to separate UI layout and control from system core functionalities. This may be realized by different alternatives, including the separation of front- and backend, a client-server concept, the Model-view-control (MVC) architecture pattern, or three-tier architecture. We have decided upon MVC architecture pattern for modeling and implementation, since it allows focusing on the UI without any interference with the system logic. For integration of UCD process into the ordinary development process, it is required to be able to translate the results of each phase in a form that can be easily merged with the development process. For this purpose, we have chosen Model-driven Development (MDD), which is well suited to integrate these needs into the development process, since semantic annotations can be easily extracted from models. Also various generating tools exist for this purpose. Figure 1 shows the relation between UCD and MDD.

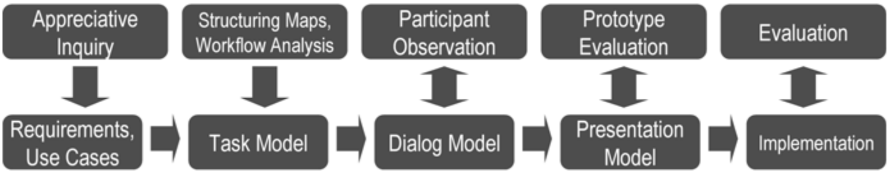

Fig. 1 Process view for UCD and MDD of UIs

4 The Concept

In our concept we have chosen a set of existing methods and standards to gather accessibility require-ments of industrial automation systems. While accessibi-lity can relate to physical design of the products or archi-tectural construction patterns, we focus on the software side and consider only the interaction interface, i.e. UI.

We refer to this set of methods as Accessibility Requirements in Design Approaches (ARDA). ARDA can be divided into two parts: 1) ARDA for the development process and 2) ARDA for the run-time behavior of the UI. Figure 2 shows an overview of the ARDA. ARDA for the development process consist of:

- **Workflow identification**: Knowledge about user's workflow is necessary to determine the relevant in-formation in the UI.
- **Relevant information**: Analysis of relevant infor-mation depending from tasks and workflow. Infor-mation is relevant if necessary for workflow.
- **Separation of functionality/usage**: Separation of data model/core-functionality and UI-presentation/ control enables multimodal concepts for usage and different layouts for particular input/output devices.
- **Architecture pattern**: Use of well-suited architec-ture pattern as MVC, Presentation-Abstraction-Control (PAC), Model-View-ViewModel (MVVM) or Model-View-Presenter (MVP), which supports the separation of core functionality and UI control.

ARDA for the run-time behavior of the UI consist of:

- **Text-based annotations**: Employment of descrip-tive annotations (e.g. text-based) on interface com-ponents and structure.
- **Multimodal interaction**: Deployment of multimo-dal interactions.
- **Enriched UI components**: Realization of communi-cation amongst interface components on their role, state, properties and changes of their role, state, and properties.
- **Serial order**: Design of interface components in a serial order – corresponding to user's workflow – to support Assistive Technology (AT) such as screen readers.
- **Clear navigation**: Structuring the interface naviga-tion distinctly and avoiding deep hierarchical struc-tures, in order to support sitemaps and breadcrumbs for instance.

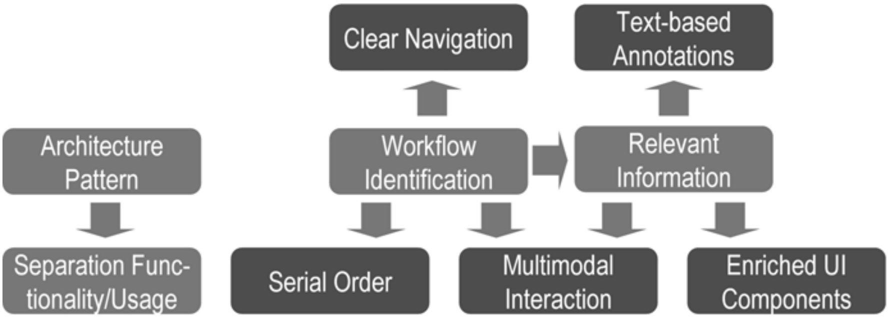

Fig. 2 Overview of ARDA

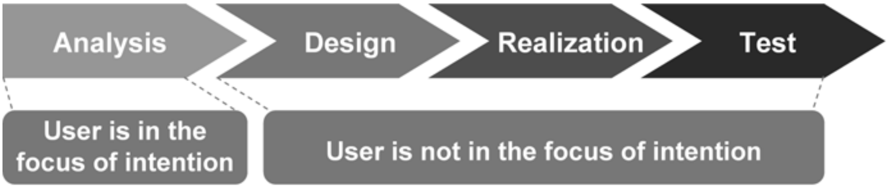

Fig. 3 Developer focus during development process

The complex requirements of accessibility are one of the major obstacles for their integration in pervasive technology. To overcome this problem the developer-user gap needs to be resolved. The classical development model – according to DIN 15226, consists of four deve-lopment phases; namely analysis, design, realization, and test (see Fig. 3). In this model, the users are being mainly considered in the analysis phase.

We adapt classical product development to UCD by investigating user-centered methodologies and methods for each development phase. We focus on the development methodology and software parts of the sys-tem. Mechanical or metallurgical aspects of such products are not addressed. Numerous approached are available out there to enhance accessibility for the end users. Such methods typically address the run-time behavior of the system and are not suitable for analysis and design. Moreover, new approaches are often still too abstract to be applied in real production. For instance, UCD is a process model, which is introduced with the objective to help better integrate the user and his functional/none-functional requirements into the development. Yet, it does not provide a concrete and systematic process, thus, it is not widely accepted by firms and companies.

Figure 4 depicts an overall view on our concept. As one of the important focuses of our research, the human-technology relation affects the accessibility factor. Technology as an instrument of human action is always a medium but not a purpose of design. Accessibility is not a simple factor in the design of UI. Beside the physical disabilities affecting user interactions, accessibility crosses more study fields such as mental models, which differ from person to person, and cultural backgrounds

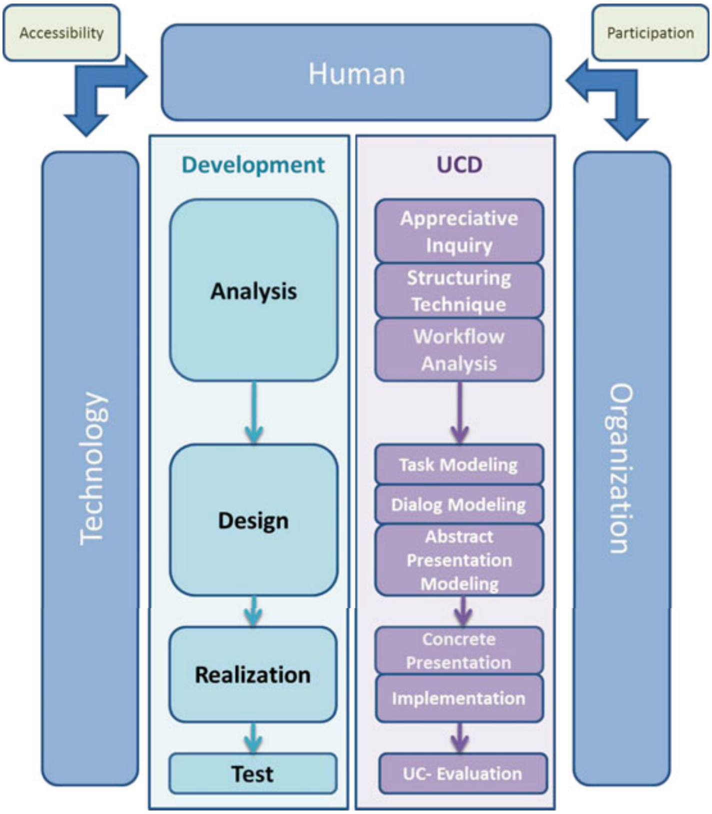

Fig. 4 Overview of the concept

(e.g. language, symbols, values, etc.). Mental Model is a concept of cognitive psychology, which was introduced by P.N. Johnson-Laird in 1983. The concept is based on the assumption that internal models of reality are a vital characteristic of human thinking. They are based on daily experience, learned knowledge and reasoning. The system needs detailed information about the place and category for the existing products. Moreover, other meta-information can be related with the products in the database e.g. category, vendor or nutrition facts. This information is also used for navigating user to the product or comparing products. We assume that the infrastructure for the information system exists, e.g. a wireless technology-based and Radio Frequency Identification (RFID) system. Customers can use applications on cellular phones e.g. barcode scanners or available devices on the basket for navigation and product information. System implementation is focused on Web technology as Hypertext Markup Language (HTML) and Java since they are widely used in implementing UIs in industrial automation systems.

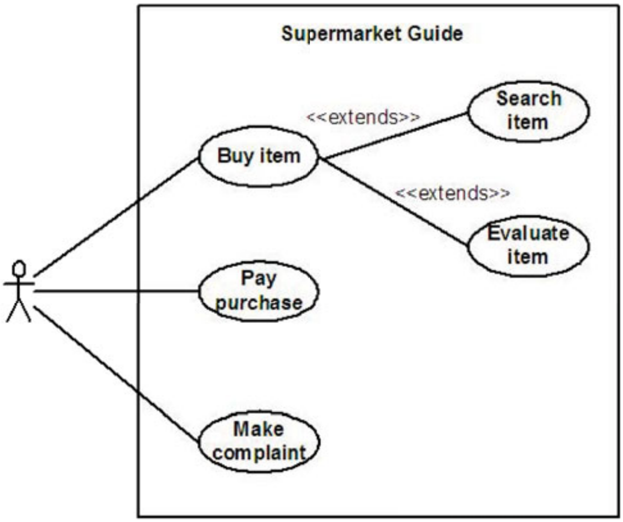

Fig. 5 Use cases for the super market guide

4.1 Analysis

Classical analysis starts with market research to find out about potential markets or the public requirements. In this process, there are usually certain classic methods being used for gathering requirements of the system, e.g. stakeholder identification and interviews. This process attempts to cover overall aspects of content and functionality as well as none-functional requirements. However, classic interviews between experts and users can only give one side of the facts. We use the Appreciative Inquiry [W3C08]. It enables detailed analysis with user integration when it may be difficult for the users to describe their needs or problems. Appreciative Inquiry is a 4-phase organizational development methodology. The four phases are: discovery, dream, design and destiny. It engages individuals within an organization or institution in its change and renewal. In a first step, well-working processes are identified with appreciative interviews (discover phase). During dream phase, processes are planned and redesigned. Finally, the destiny phase serves for implementation and execution of the new design. Here, interactions of users with and without visual impairment are considered. The requirements are documented as use cases with diagrams (see Fig. 5) and textual descriptions.

The next step is the analysis of user's activities related to the documented use cases and afterwards the modeling of an appropriate workflow. Integrative design must respect different ways of doing things. Users have mental representations and expectations of workflow to follow their activities. These mental models of workflow are analyzed with an easy-to-learn structuring technique. Structuring technique allows users to describe their imagination with words and drawings and is therefore a well-suited method to obtain user's mental model of activities. The workflow analysis can be extended with participant observation and structured interviews. Also,

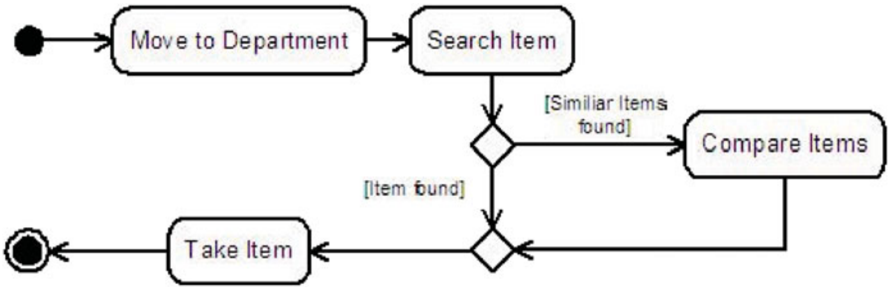

Fig. 6 Modes of the use case *Buy item*

interview and observation are the first choice methods to analyze the mental models of visually impaired users.

4.2 Task Modeling

The modeling process starts with workflow description the task modeling. Use cases are detailed with UML activity diagrams and user's input comes from the structuring technique maps. User's side of the interaction is described with modes. A mode of usage is a particular context of an activity. The machine context will not be changed within one mode. Modes may have submodes e.g. for auxiliary functions or navigation. But only one main mode is active at a certain time and deep nesting of modes is avoided to facilitate user's interaction. Modes are well-suited to encapsulate the Human-machine Interaction (HMI) and identifying user's modes is a good preparation for the dialog modeling later-on. A UML activity diagram is well-suited to model user navigation from mode to mode. Figure 6 shows the modes for the use case Buy item.

At first, the user moves towards a particular product department. In the department, he searches the product. If he can find his product, then he will take it. Otherwise, he will compare similar products and take a suited replacement. Next step is a detailed description/modeling of the supported workflow. The modes are refined with user's basic actions. Actions are the smallest (atomic) activities of the user which still have motive and intention. Generally, they are not physical operations. Physical operations – such as moving a mouse or pressing a key – define the most precise level in the workflow. Here, they are not part of task modeling to keep it independent from single input/output devices. Figure 7 shows the resulting activity diagram for the use case Buy Item.

The user observes his environment and categorizes the products. When the products are similar to the searched one he starts to search the product itself in the department. Action modeling can be facilitated by classifying the basic activities of the user. Action classification is domain-specific. Reuther's [Reu03] classification of atomic use objects for UIs of automation systems includes input, edit, select, ac-

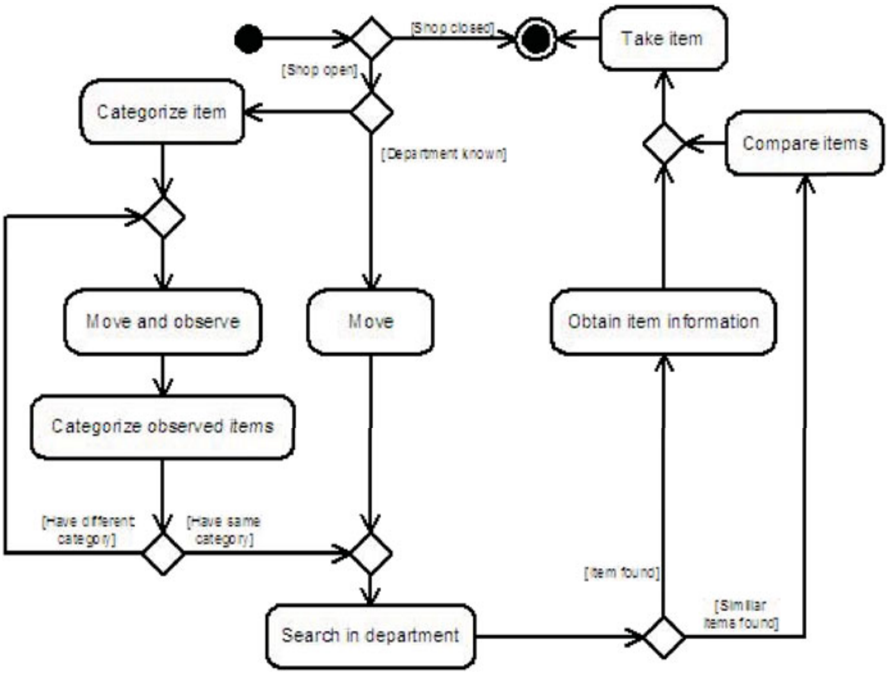

Fig. 7 Actions of the use case *Buy item*

tivate and inform. The modeling of workflow enables the determination of relevant information about the related objects. Later on, this information must be completely included in the device-independent description of HMI dialogs to realize device-independence and therefore accessible HMI.

4.3 Dialog Modeling

Dialog modeling connects the human side of tasks and workflow with the applications part of UI actions and components. It mediates between the task model and presentation model. Accessibility has to be respected to enforce all people in usage of the application. One basic concept is the parallelization of HMI with different modalities of in- and output. Typically, visual, acoustical and haptical modalities are available. Using more than one modality for the presentation and control of the same information enables even users with sensory or physical disabilities the use of the UI. Multimodal HMI models allow the reuse of communication design for different UIs including AT such as Braille devices or Speech recognition. The UI may have various states within the same user mode, which are not always visible for the user. State charts or activity diagrams in UML are appropriate to model the behavior of interface components. Dialog modeling can follow different strategies of HMI such as universal or multimodal design. Universal design means that per-

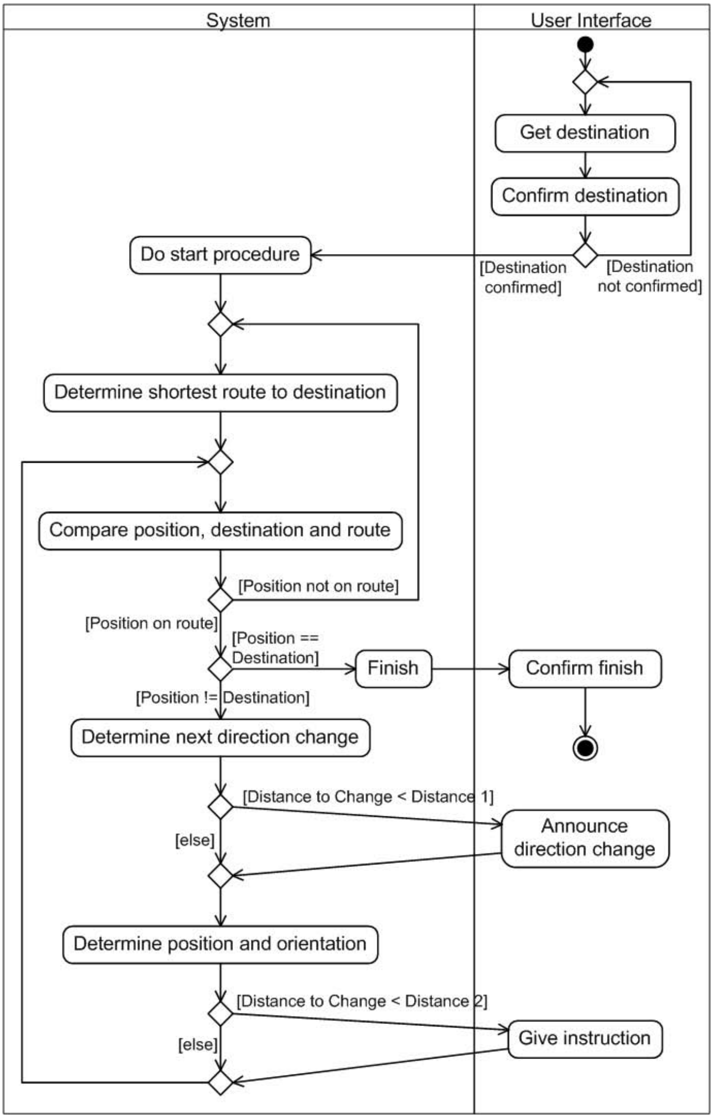

Fig. 8 System and UI actions for the navigation to the department

ception and control of all relevant information in the UI is independent from in- or output devices. Multimodal design includes the use of different modalities as visual, acoustical or haptical to realize the UI functionalities. The example in Fig. 8 shows the actions of the UI and the system while guiding the customer to a product department in the supermarket. Left-sided the system actions are shown and right-sided the actions of the UI. The vertical order is not chronically. The UI actions are modeled device-independent.

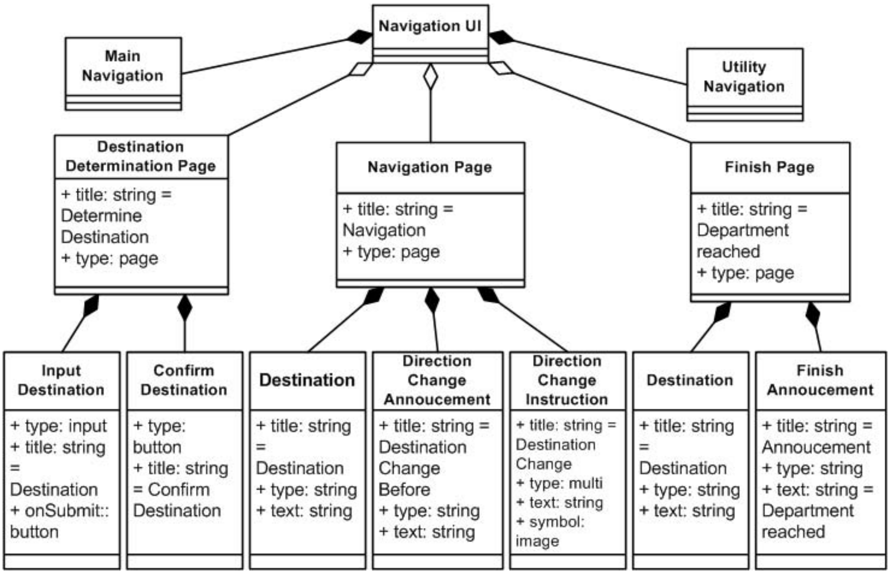

Fig. 9 Abstract presentation model for navigation UI

4.4 Abstract Presentation Modeling

Abstract Presentation Modeling is the last part of the modeling process and has to respect accessibility issues as well. The components of the UI serve as mediators between the user and the application. Therefore, they are called mediators. Mediators have in- and output connections for both sides – user and application (MVC control). Modeling of internal UI states serves to detail UI behavior within the application. The Abstract Presentation Model (APM) describes the UI components and actions semantically. The model annotations are used later-on to extend UI components with text-based annotations for AT support. Static UI hierarchy is modeled with class diagrams in UML notation. Navigation is taken from the model of modes (see Fig. 6). Modes and mediators have attributes, which are mapped to HTML elements, and attributes later on to describe metadata and device-independent properties. Device-independent event-handler and WAI-ARIA-like [W3C09] elements are used to describe the behavior of the UI during runtime. Abstract UI components are anchor, link, text, buttons, image, text input, choice, container etc. Attributes are used to declare necessary metadata for UI elements such as title, name, type etc. Figure 9 shows the APM for the navigation UI including three pages to determine the destination, to navigate and to announce that the customer has reached the desired product department offering further functionalities.

4.5 Concrete Presentation Design and Implementation

The presentation modeling and application layout them-selves are not part of the modeling process. For the implementation of the declared models, an existing Web frame-work is used. The frameworks for Web application development support the usage of accessible UI components.

Two Java Web frameworks with MVC architecture are Apache MyFaces (AMF) including the Trinidad and Tobago subprojects and the Google Web Toolkit (GWT). AMF Trinidad and GWT have built-in support for accessible UI elements. GWT implements more client-side functionality to obtain application behavior similar to desktop applications. Furthermore, accessible notifications about roles, states and changes of UI components are included. AMF is an open source implementation of SUN's specification for Java Server Faces (JSF). Some subprojects extend functionality of JSF such as Tobago, Tomahawk or Trinidad. The Trinidad library – formerly known as Oracle's ADF Faces – enriches AMF with more than 100 UI components including simpler components like tables or trees as well as more complex components like calendars. Additionally, accessibility for UI components is supported and other features such as a dialog framework or pageFlowScope – a bean scope between the request and session scope of JSF. AMF Trinidad uses its own markup elements. The markup of the resulting HTML page is completely encapsulated. UI modes from modeling are implemented as JSF-views. Another important aspect of HMI is the modality of interaction. In many cases, a multimodal interaction provides more flexibility in interacting with an UI. It is useful to overcome certain limitations of the users in advance and corresponds to a higher accessibility. For instance, providing the voice input along with classical keyboard and mouse solutions is suitable for visually impaired users. Development of software supporting multimodal interaction requires a standard that supports including various interactions channels. Currently, XHTML+Voice (aka. X+V) is one of the pioneer standards, and open source software, which supports multimodality. VoiceXML 2.0, Speech Synthesis Markup Language (SSML 1.0), Speech Recognition Grammar Format (SRGF) and XML events can be integrated using XHTML modularization to bring spoken interaction to the Web. Using such technologies, a portable and accessible technology can be employed. In the case of visually impaired customers in a supermarket, this can be perfectly combined with cell phones or other embedded systems for online support of the customer during shopping.

5 Conclusions and Outlook

We have discussed the potential of UCD and MDE in maintaining accessibility to UI, by assessing the accessibility requirements to the development process. Having focused on the early development stages, i.e. analysis and design phase, we have investigated suitable methods and technologies, which can assist developers by designing an accessible UI for industrial automation systems. The proposed concept is based on the survey made on the state of the art and consists of a set of suitable methods. It provides a parallel process to the development process, while considering human, technology, and organization and their interconnections. The parallel process is based on the UCD and uses MDE instructions. It runs along the development and feeds the development process with methods to assess accessibility requirements of the end UI. The MDE nature of the concept provides an easy integration of the results in the main development process. Our plan for the future is to evaluate the concept using a real case study. Therefore, two scenarios have been designed: accessible maintenance of a high bay rack system and interaction of a blind user with a Web-based travel information system.

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Merging Web Accessibility and Usability by Patterns

Helmut Vieritz, Daniel Schilberg, Sabina Jeschke

Abstract Nowadays, usability and accessibility are two important quality aspects of user interfaces (UIs). But in research and development, both are sometimes accounted as unity and sometimes as contradiction. Understanding Web accessibility as an essential part of usability, here an approach is given to clarify the relationship of both. Therefore,

- a pattern approach was chosen to meet the practical requirements of UI designers which are often not familiar with accessibility needs,
- a collection of patterns for human-computer interaction (HCI) has been extended with accessibility requirements and
- finally a pattern example illustrates the cooperation of usability and accessibility in detail.

Key words: Accessability, Web Accessibility Pattern, Usability

1 Introduction

Usability and accessibility as well are two growing factors in product design. The use of modern technology is mostly not limited by product functionality but UI design and usage under limiting conditions. Limits can be set by users with special needs as people with disabilities or elderly people, technology as cellular phones etc. or an environment with noise or bright light.

But, the relationship of accessibility and usability is still not clarified. The usability definition most widely adopted was given by Nielsen [Nie93] and is focused on learnability, efficiency, memorability, few errors and users' satisfaction. The common understanding of accessibility defines it as access to and controll of all in-

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formation for all users. Even people with impairments can perceive, understand, navigate through and interact with the (Web) application [Ini05]. Since these definitions are focused on different aspects of usage – general quality of usage versus access to information – the relationship is not simply given. Accessible applications have positive impacts for all users. Therefore, accessibility is often seen as a part of usability [Shn00]. Integrating usability and accessibility issues in the software design and development process is a complex challenge. Additionally, different (Web) technologies raise the needed knowledge and costs.

The presented research has the objective to facilitate the integretation of accessibility requirements in practical work. Modern approaches of application development are focused on UI design and usability since the quality of UI has a growing impact on the commercial success of products. But until now, accessibility is mostly not seen as an important commercial criterion for better product design and has not the same impact. A solution may be to see accessibility from usability point of view and to give more support for the early design process of UIs then existing recommandations as the *Web Content Accessibility Guidelines* (WCAG 2.0) [Wor08] can do. The presented approach adapts the needs of accessibility to UI design which is focused on usability. Therefore, a pattern framework of interaction pattern has been extended with the requirements for accessible UIs.

2 Related Work

Patterns for usability and interaction design are broadly discussed in research and practice. Some frameworks already exist. Borchers [Bor01] has developed and detailed discussed a pattern framework which is focused on an interactive music exhibition. Folmer et al. [FvGB04] has published a framework of software architecture-relevant patterns and Graham [Gra03] has published a pattern language for Web usability. Other pattern languages for interaction design can be found in [van02, Tid05, MVM09]. In these frameworks, accessibility is sometimes mentioned but not integrated in detail. For example, in [FvGB04] accessibility is reduced to multimodal use. Few papers exist for Web accessibility patterns [Ihm07, VJP09] which do not rely on usability. Abraham [Abr06] presents a case-based reasoning (CBR) approach to improve the accessibility of interaction patterns. His approach does not clarify the relationship to accessibility standards as WCAG. In general, an overall approach to merge usability and accessibility is still missing.

3 Accessibility and Usability by Patterns

Pattern languages are a well-suited method to explain basic idea without the technological overhead. Patterns have been introduced in urban architecture by Christopher Alexander in 1977 [AIS77]. Nowadays, they are widely known in software development and HCI as well. An *usability* or *interaction pattern language* in HCI is a collection of recommendations for the design of usable UIs. A *pattern* is a preformal construct which gives a best practice solution for a repeating problem. It is described in a defined structure such as problem, context and solution. Typical categories are:

- A name for the pattern which is memorizable and unique
- A short statement of the problem
- A description of pattern context
- A solution for the pattern which explains the problem and its solution in detail
- A graphical depiction for pattern application which underlines the pattern idea.

Additionally, a *pattern framework* includes structure and relationships between patterns. Until now, attempts of stronger formalization with e.g. the *Pattern Language Markup Language* (PLML) were not successful.

Folmer et al. [FvGB04] give an overview for common usability patterns (see Fig. 1). This framework was chosen for current research of accessibility influence on software architecture (not discussed here). *Usability attributes* are precise and measurable criteria of the abstract concept. There are four common attributes: efficiency, reliability, satisfaction and learnability. Heuristics and design principles are embodied in *usability properties*. Fifteen typical architecture-relevant usability patterns are described.

Using the WCAG 2.0-recommendations [Wor08] a similar classification for accessibility patterns can be derived. The WCAG-guidelines are well-suited to form a pattern language since they are technology-independent and based on a long discussion between all interest groups. The four basic attributes are perceivable, operable, understandable and robust. The twelve different main guidelines are taken as basic principles of accessibility. Here, for better overview only the 25 level A[1] guidelines are shown. Changing by the additional guidelines for level AA and AAA is small since they only enlarge often practical and technological efforts e.g. captions for live stream additional to pre-recorded multimedia content.

After selection and classification of usability and accessibility patterns they are mapped on each other. The mapping of an accessibility pattern to an interaction pattern is sometimes caused by the same idea of solution and sometimes by the same type of pattern context. Some accessibility patterns have a context which is valid in many situations. For better overview they are included without mapping showing that they have to be integrated by all usability patterns. The relationship between both is best presented from usability point of view. The mappings show which accessibility requirements have to be respected in the context of usability patterns. The absence of contradictions underlines that accessible control of user interfaces is not counterpart of usability. The usability pattern structure is extended with categories

[1] WCAG have three conformance levels from A (lowest) to AAA (highest) to correspond to different needs of groups and situations.

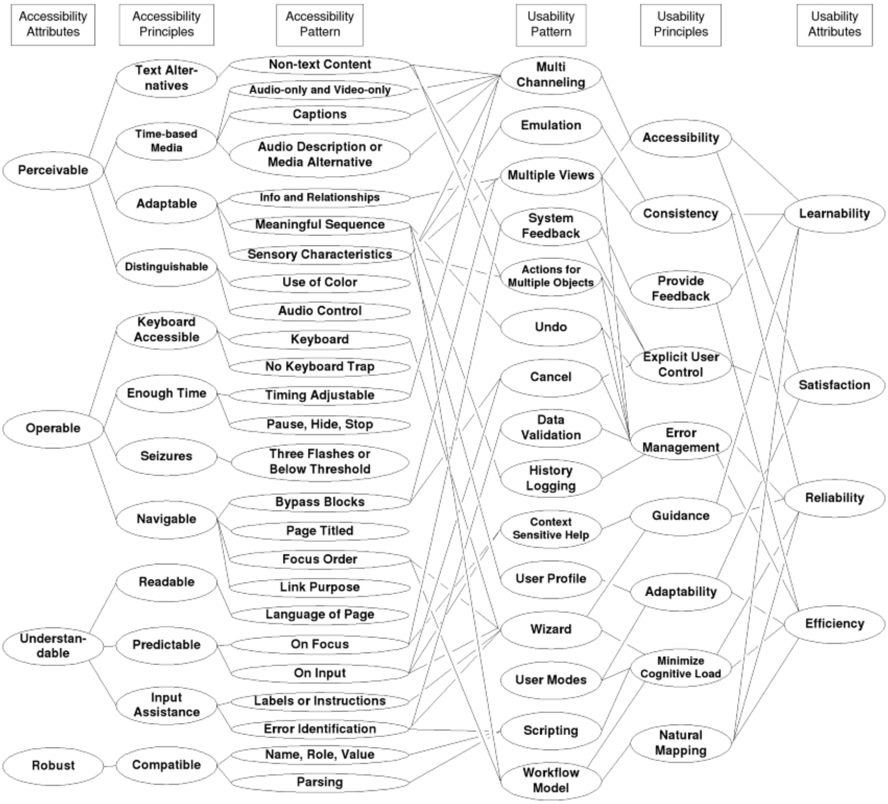

Fig. 1 A pattern collection for accessibility and usability (derived from [Wor08, FvGB04], mappings reduced)

Relevant Accessibility Patterns, *Main Accessibility Issues* and an additional illustration to include the requirements of accessibility in UI design. These three additional categories explain and illustrate how the proposed solution for an usable UI design can be made accessible as well.

4 A Pattern Example

The usability pattern *Wizard* is given as an illustrating example. Wizards in UI design are well-known in many situations such as shipping and payment dialogs in online shops or dialogs for the conversion of file formats. A Wizard-situation is characterized by a high level of interactivity since the user needs some informa-

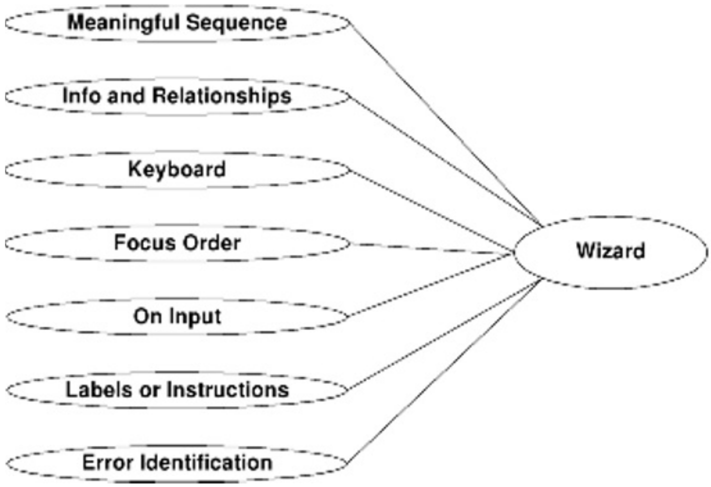

Fig. 2 Accessibility patterns for interaction pattern *Wizard* (selection from Fig. 1)

tion and has to make decisions. Therefore, it include access to information and UI control as well. At first, the pattern example describes the organization of a wizard and completes the description with the accessibility requirements. More pattern from the library can be found on the project Web site http://www.inamosys.de. Figure 2 shows the accessibility patterns which are relevant for the Wizard pattern.

4.1 Pattern Wizard

Problem

The user has to make several decisions to achieve a single goal. He may need additional information, previews or examples about the result of decisions.

Context

Infrequent complex tasks need to be performed by non-expert users. The task consists of several subtasks (3–10) each containing a decision. The user wants to complete the task but may be not familiar with or interested in the subtasks. The single steps may rely on each other and they are ordered.

Illustration

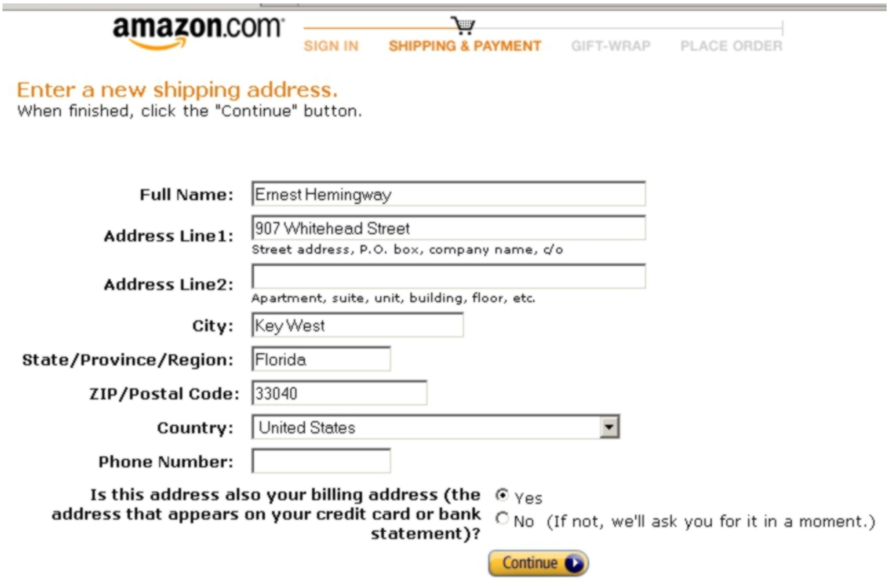

Fig. 3 Wizard for shipping and payment on Amazons Web page

Solution

The user is taken through the entire task step by step (see Fig. 3). Existing and completed steps are shown. The user is informed about the task goal from beginning on and that several decisions are to be made. Widgets are provided for navigation through the entire task. The user can recognize that a subtask has to be fulfilled before the next is available. Revising of decisions is possible by back navigation to a previous subtask. The user is given feedback for the purpose of decisions. Explanations, previews or examples clarify the results. The final result is shown. If possible, appropriate default settings and short cuts accelerate and simplify the process for experienced users.

Relevant Accessibility Pattern

Typically, a wizard uses forms to get needed information from the user. Buttons serve to finish the single steps. To be accessible, the different input fields of the form must be labeled, accessible by keybord and the order of access must correspond with the workflow. Error identification and input help should be available and accessible as well.

Relevant accessibility patterns are (a) *Meaningful Sequence*, (b) *Keyboard*, (c) *Focus Order*, (d) *On Input*, (e) *Error Identification* and (f) *Labels or Instructions* (see Fig. 4).

Solution Illustration

Fig. 4 Accessibility requirements for wizard

Main Accessibility Issues

Widgets are labeled and order corresponds with workflow. All functionality is available by keyboard. Name and role of interface components can be programmatically determined when scripts are used. User is advised in advance when changing the setting or focusing of user interface components does automatically cause a change of context.

5 Conclusions

The objective of the presented approach is the extention of an usability-driven UI design with the requirements of accessibility. A pattern approach was used to describe the main ideas independent from used UI platform. It gives software architects and developers an easy and quick way to understand the basic ideas of accessible user interfaces and helps them to see usability and accessibility not as a contradiction. The extension with new interaction patterns is easy.

The approach is still limited to be only a collection of pattern. Further work will be done on structure, completeness and relationships between pattern to built up a pattern framework which merges usability and accessibility in practical UI design. Furthermore, the pattern collection serves for analysis of accessibility influence on software architecture in usage-driven UI design.

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User-Centered Design of Accessible Web and Automation Systems

Helmut Vieritz, Farzan Yazdi, Daniel Schilberg, Peter Göhner, Sabina Jeschke

Abstract During the past decades, Web applications and industrial automation systems – and their combination in e.g. pervasive computing – have gained more and more importance in our daily life. However until now, user interface accessibility remains as an important quality aspect and a challenge for implementation. The majority of accessibility requirements are shared between these types of systems. This paper presents a research on user-centered design and model-driven development of accessible user interfaces. The approach integrates the product requirements of Web and industrial automation systems. The use of different interface models enables the description of particular UI aspects as structure or behavior. User-centered design facilitates the integration of user-driven accessibility requirements. The focus on the requirements of software development processes for Web and automation systems shows that research on accessible user interfaces has to consider the requirements of product analysis and design. Additionally, upcoming daily use in pervasive computing requires a comparison of requirements for both system types.

Key words: Accessibility, User-Centered Design, User Interface Modeling, Model-Driven Design

1 Introduction

During the past decades, Web applications and industrial automation systems[1] – and their combination – have gained more and more importance in our daily life. Research on Ambient Assisted Living (AAL) demonstrates new possibilities in daily

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[1] With industrial automation systems we refer to products such as ticket vending machines, washing machines or automated teller machines (ATM) systems.

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life use of all people. However until now, the usage of these applications is often restricted for people with disabilities such as blind or deaf people since the User Interface (UI) design was not made with respect to their needs.

Existing accessibility recommendations as the Web Content Accessibility Guidelines (WCAG 2.0) [Wor08] address mainly the run-time behavior. They are difficult to adapt to the requirements of early product development phases. Additionally, they are mainly created for Web applications.

Despite the importance of accessibility, it is still a big challenge integrating it to the industrial automation systems, due to reasons as the variety of user requirements for different groups or the difference between developer's mindset with that of the user. Additionally, restrictions may come from limited UI technology as smart phones with small screens or obstructive environment conditions as noise. Thus, accessible usage includes limited technology as mobile devices and restricting environments.

Both, industrial automation systems and Web applications share similar accessibility requirements. Here, the accessibility requirements are summarized in five criteria derived from the WCAG 2.0 [Wor08], the WAI-Rich Internet Applications (WAI-ARIA) [Wor09] and further research:

A) Metadata for documents describes author, title, document relations etc.
B) Navigation techniques as main or utility navigation, breadcrumbs or sitemap are supported.
C) Navigation through documents as skip links, access keys or short cuts can be given.
D) The UI model can describe user's workflow and serial order of UI components to assure that the order of interface components corresponds with user's workflow.
E) UI elements are described with role, state and state changing (behavior).

Often, User-centered Design (UCD) is recommended to ameliorate product accessibility [Swe08, Hen07, Deu02]. User-centered design is focused on user's needs and limitations during all the phases of the design process. Originally, UCD was intended to optimize the usability of products. Meanwhile, accessibility is seen as an essential part of usability and it is proposed to join users with disabilities in analysis, design and evaluation to enhance product accessibility [Hen07]. The adaption of recommendations as well as the integration of users with disabilities in design requires expert knowledge. Additionally, systematic processes are lacking.

The focus of the presented research is the impact of product accessibility requirements on modern software development processes for Web software or automation systems. To overcome the mentioned problems, we propose user task analysis and modeling in early product design. Abstract task modeling allows describing user's workflow independent from the input and output technology. It is used in modeling multi-target and multimodality UIs [G. 02].

Accessibility means that the products are usable for all users independent from their particular capabilities or age and without assistance by other persons [Deu02] including free perception and control of all relevant information [Wor08]. Relevant information refers to those being needed by the user to follow the intended workflow constituted by activities, actions and their relations. Therefore, the UI itself must assist the user to fulfill his or her working tasks and the usage must be easy to learn.

2 Related Research

Meanwhile, accessibility in product design is addressed by numerous international and national recommendations (e.g. [Wor08, Wor09] and [Swe08]). The WCAG [Wor08] have the greatest impact on scientific research and discussion.

Accessibility in UCD is described by Henry [Hen07] focusing on integration of users with disabilities in analysis and design and modeling is not included.

Approaches for Model-driven Design (MDD) in UI development can be classified in more practical or analytical concepts. Practical approaches are focused on usage in platform-independent development of UIs including development tools. Some examples are User Interface Markup Language (UIML) [UIM09], User Interface Description Language (UIDL) [UID08], and Extensible Application Markup Language (XAML) [Mic10a]. Recent technologies as Microsoft Silverlight or Adobe Flex provide the separation of UI layout from UI behavior as well as from system core functionalities.

Analytical approaches are more abstract and include often a metamodel for all UI aspects, which describes UI structure, components, behavior, navigation, domain, and resources. Examples are User Interface Extensible Markup Language (UsiXML) [Usi10], useML [Reu03], Unified Modeling Language for Interactive Applications (UMLi) [dS02], Task Modeling Language (TaskML) [Hal02] and Dialog Modeling Language (DiaMODL) [Hal02]. However, analytical approaches are still under research and there is a lack of tool support for implementation.

Despite the promising potential, only few publications address the integration of accessibility in MDD of UIs. The Dante project [YHGS04] uses annotations in UI modeling to improve the navigation capabilities for visually impaired users. The authors have discussed particular aspects of UCD and MDD for accessible UIs in former publications (e.g. [PSS+08, JVP08]). The integration of different target platforms as the Web and mobile technologies is also addressed by the AEGIS EU-Project and the Raising the floor initiave.

3 Web Applications and Industrial Automation Systems

3.1 Accessibility Requirements

In this paper, Web applications and industrial automation systems are addressed. Their usage is more and more merged in pervasive computing e.g. navigation systems. Despite of obvious differences, many similarities form the ground for shared requirements and solutions in accessibility design. Some important similarities are:

- User disabilities, technological or environmental limitations lead to restrictions in Human-computer Interaction (HCI) e.g. acoustic interaction may be impossible.
- The combined use and limited interaction capabilities results in identical accessibility problems such as touchscreens require an alternative information representation for blind users.
- The spreading usage in daily life is associated with different user roles and characteristics.
- User and system workflow is automatized.
- Web technologies as HTML are used for UI implementation.

Regarding accessibility, important differences are:

- Industrial automation systems have often limited resources whereas Web applications are running on powerful clients and servers.
- Industrial automation systems have built-in UIs whereas interaction devices for Web applications e.g. browsers are running as separated clients allowing the usage of Assistive Technology (AT) for people with disabilities.
- Accessible Web content is typically a requirement of users with disabilities whereas for automation systems, accessibility is often driven by limited UI technologies or environment restrictions. Nevertheless, the requirements are similar and solutions can be adapted to the other field (see [Wor]).

We have used the WCAG to analyze and compare accessible HCI for Web and automation systems. A similar work was already done with the W3C Mobile Web Best Practices 1.0 [Wor]. More than 70 % of the guidelines could be employed for the industrial automation system [Wor]. Hence, our concept uses WCAG as the basis to address the critical accessibility issues.

3.2 Model-Driven Design

A generic approach for accessible Web and automation systems needs a process model – User-centered Design process – and a structural model – the architecture model – for the development of the application. Model-driven design is very common in software engineering e.g. for automation systems. In Web development, MDD is already addressed by research activities. However, fast developing Web technologies and their diversity as well as the importance of creative aspects as layout impede the usage of MDD in Web engineering.

Model-driven design of UIs allows the abstract description of particular aspects of UI behavior or structure. Meanwhile, the Unified Modeling Language 2 (UML, [Obj11]) is the lingua franca for modeling and graphical notation in software design. Here, UML diagrams are used to describe the different models of the UI. The abstract description of UI behavior provides a universal design making the usage of the UI independent from particular input and output devices.

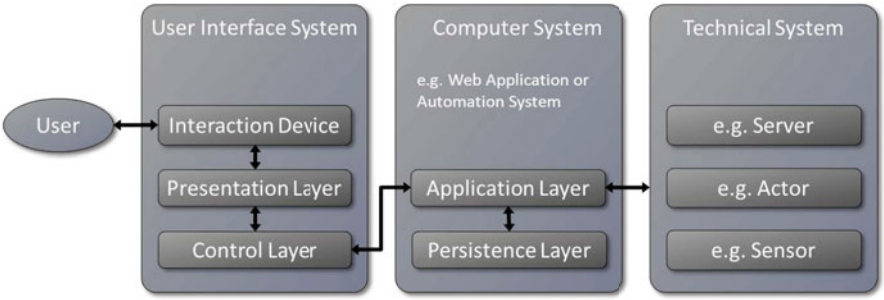

Fig. 1 Basic architecture for accessible systems

3.2.1 Generic Architecture Model.

A common architecture model is needed to merge the development processes for Web applications and industrial automation systems. The generic architecture of both is slightly different. Web applications are typically designed with layers for presentation, application logic and data persistence (three-tier architecture) e.g. the Model-View-Control (MVC) architecture pattern.

Otherwise, industrial automation systems are separated into the technical system which is automatized, the automation system itself and UI system [LG99]. The technical system includes all hard- and software which is needed to transform any kind of energy e.g. a heating system or matter e.g. a washing machine. The automation system controls the processes of the technical system e.g. to obtain a time-depending behavior or to communicate with other systems. The UI system is responsible for all aspects of HCI.

To bring Web and automation systems together, we have merged the layer architecture with the three main components and called them UI System, Computer System and Technical System. Figure 1 shows the generic application architecture which is applicable for Web and automation systems.

The architecture combines common three-tier architecture with a separation of automation system and technical system. The UI system consists of an interaction device a presentation and a control layer. The interaction device may be a built-in UI as well as a client-based browser or screen reader. The presentation layer is responsible for HCI. Additionally, a control layer manages user control of the whole system and mediates between the UI and the computer system. The computer system compasses the application functionalities or the automation core and the persistence layer if data storing is needed. The technical system includes the complete hardware and software of the automatized system e.g. a ticket vending machine. The technical system of a Web application is the server operating system and the hardware.

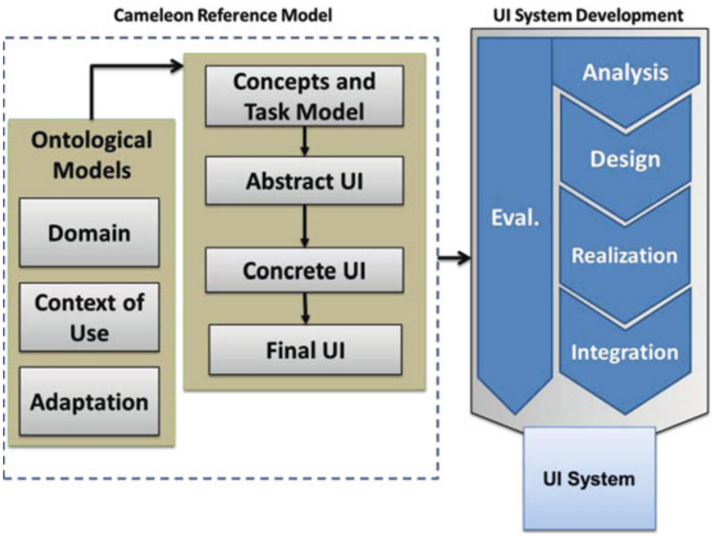

Fig. 2 Cameleon reference model [G. 02] in UI modeling

3.2.2 User-centered Design for Human-computer Interaction.

In this paper, we will focus on UI analysis and design for accessible UI systems. Regarding their UI, UCD is a promising approach for the UI development of Web and industrial automation systems, since both systems share similar accessibility requirements (see Sect. 3.1).

Our modeling concept was developed in reference to the Cameleon Reference Model for UI modeling [G. 02]. The reference model is designed to model UIs for multiple classes of users, platforms and environments (multi-target). It covers design and run-time phases of UIs. Figure 2 shows the four level model hierarchy for design.

The highest level concepts and tasks allow the combination of design concepts with user tasks. The Abstract User Interface (AUI) model describes domain concepts independent from particular targets and input/output devices. It provides a semantical description of HCI with modes and dialogs. The Concrete User Interface (CUI) model gives an interactor-dependent description of the UI. Multimodal adaption of HCI can be integrated to support interaction modalities as visual, acoustical or haptic interaction. The Final User Interface (FUI) is the transformation of the CUI into source code as Java or HTML.

The Cameleon Reference Model is used as a master pattern for the design of essential UI models. Three types of models are essential [Kri04] – the task (see Sect. 3.3), the dialog (see Sect. 3.4) and the presentation model (see Sect. 3.5):

- The task model represents user's part of HCI. It comprises use cases, scenarios, activities, workflow etc.

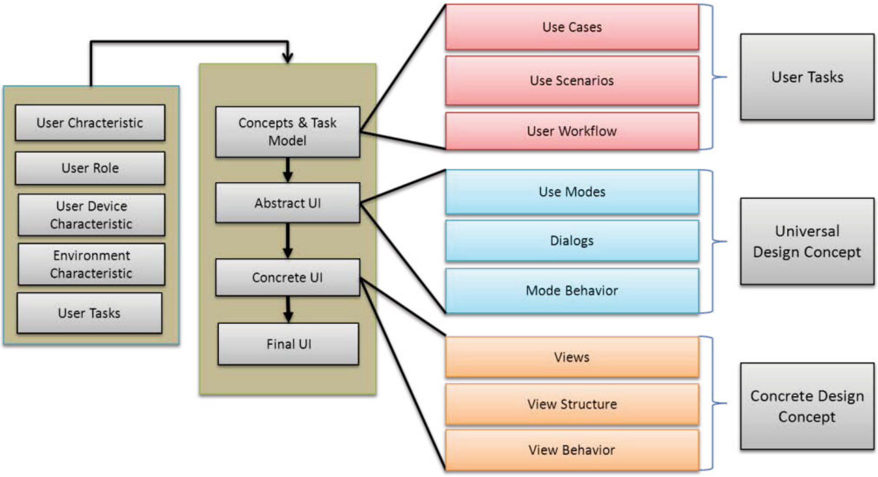

Fig. 3 Concept for UI Modeling

- In the middle, the dialog model mediates between human and system activities. It describes HCI with modes, dialogs and basic interactions and transforms information from the active part of the user to the reactive behavior of the UI.
- The presentation model is a semantical description of the UI. It includes navigation, views, UI components, roles, behavior etc.

Additional models as the user model allow the design of more complex UI applications. Figure 3 gives an overview for the integration of essential modeling needs into the reference model.

In a first step, requirement gathering helps to define design goals for user activities and system functionalities. Interaction concepts and user tasks are described by the task model with use cases, scenarios and activity diagrams (see Sect. 3.3). Thereafter, the dialog model defines the abstract design of HCI with modes and interaction sequences (dialogs). A complete and abstract description of all essential HCI aspects provides the developer with a universal design concept for an accessible UI (see Sect. 3.4). Finally, the presentation model allows the detailing of navigation, views and UI components regarding the visual, acoustic or haptic modality of HCI (see Sect. 3.5).

3.3 Task Modeling

In the task model, activities as the main steps of user's workflow are described and detailed with user's workflow and basic actions. In UML, activities are sets of user actions. User-centered Design is often based on the analysis of user's tasks and workflow. Use cases and scenarios are detailed with activities and actions. The

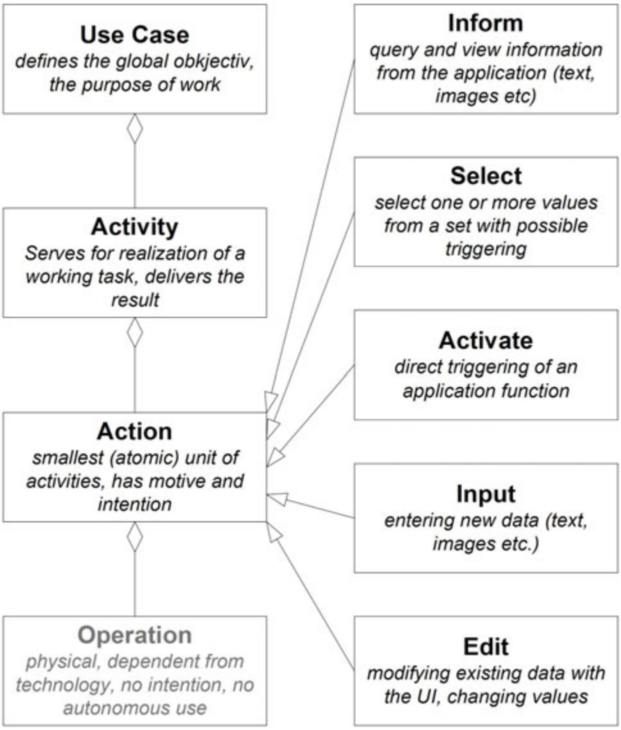

Fig. 4 Task hierarchy and elementary user actions

useML approach [Reu03] provides a simple but powerful set of basic actions – so-called elementary use objects. Here, it is extended with graphical workflow description, constraints and UML notation. Figure 4 shows the structural classes of this task model.

The task model includes use cases, activities and basic actions (left side). Use cases are decomposed into activities and elementary actions further on. Not included are physical operations as mouse moving or key pressing since they are not independent from in-/output device. Thus, the description of user activities in task modeling remains independent from visual, acoustic or haptic interaction modality.

Atomic user actions represent the basic level of task modeling. A set of five predefined actions [Reu03] (see Fig. 4, right side) facilitates the modeling with UML activity diagrams. They are named: Inform, Select, Activate, Input and Edit.

In UML 2, particular diagrams are well-suited for the graphical notation of models. The active part of the user can be modeled with use case diagrams and activity diagrams. The reactive behavior of the UI is described in state chart diagrams. Structural aspects are notated with class diagrams. Last but not least, sequence diagrams describe the sequential order of interaction.

Task modeling with UML allows not only the hierarchical decomposition of user activities into basic actions but also the modeling of different workflow types as serialized, parallelized, synchronized or competing. Even constraints and decisions are supported.

Most aspects of task modeling are shared between Web and automation systems. Typically, Web applications are dealing with complex information for the user whereas automation systems have decided sets of functionalities. The task model supports both task characteristics.

3.4 Dialog Modeling

The AUI represents the dialog model. Human-computer interaction is described with dialogs and modes of usage. Similar activities allow their combination within modes of usage as an editor for different types of texts. A mode of interaction with the UI provides a particular context for usage and only a certain set of user actions is allowed. Modes are sets of UI states [Thi10] and possible user actions. A specific action has a consistent effect within a given mode. Usability and accessibility requires an elaborated mode design. Navigation in application can be modeled as the change of mode. Finally, the AUI is focused on the semantic description of the UI and represents a universal design of the UI which can be used with different type of input/output devices as displays, screen readers, a mouse or keyboard.

Dialog modeling supports Web applications as well as industrial automation systems. Typically, a Web application has more dialogs or modes but is less restricted in the capabilities regarding visual, acoustic or haptic interaction modality. Thus, the universal design concept is better suited for Web applications than for automation systems.

3.5 Presentation Modeling

In the presentation model, the modes and dialogs are represented as views, the internal structure of views and UI components. A view is a single representation of the application UI at one time. Its UI components enable a particular set of user actions which correspond with context of mode and usage. A view is often but not necessarily assigned to a file as an HTML file or a Java object as a view controller. Navigation is provided with main and utility navigation, a sitemap, breadcrumbs or metadata about view relations.

Accessible main and utility navigation as well as a sitemap are additional accessibility requirements in modeling. They provide orientation, overview and navigation through the application interface. Navigation and sitemap facilitate the user access. User orientation (especially with AT) is easier if modes are mapped to single views.

For UI programming the object-oriented programming paradigm is extended with events to describe UI reactions and behavior on user activities. This programming paradigm is called event-driven programming. Therefore, UML class descriptions are extended with events (beside attributes and methods). To meet accessibility, only device-independent event handler as OnFocus or OnActivate are used. WAI-ARIA elements are used to describe the UI behavior during runtime.

The hierarchy of UI components is described with a class diagram and UI behavior with state chart diagrams. Even, the class model allows the description of component hierarchy or serial order of elements.

UI Components may be containers or single elements. UI containers as lists, table, articles, trees etc. consists of elements which are the basic components as buttons, headings, paragraphs, sliders, links etc. Here, the UI components for the presentation modeling are derived from recent UI development frameworks as Google Web Toolkit (GWT) [Goo10], Microsoft Expression Blend (based on Silverlight and XAML) [Mic10b] or Java Server Faces (JSF) [Ora10] implementations. These frameworks are focused one the design of interactive Web-based UIs and provide interactive components exceeding hypertext markup as HTML with e.g. color or date picker.

The MVC architecture pattern separates database design (model) from control and UI (view). The separation of UI and application design is well-suited to implement the user-driven models for the UI. Meanwhile, frameworks for Web application development support the usage of accessible UI components. Here, Web frameworks are evaluated. The evaluation has included the capabilities for UI development, tools for implementation, support for accessibility design with WCAG and WAI-ARIA etc. The JSF-technology (e.g. Apache MyFaces (AMF) including Trinidad and Tobago subprojects) and the GWT provide generic accessibility support. The Web frameworks combine the MVC architecture pattern with libraries of UI components. MyFaces is an open source implementation of JSF. MyFaces Trinidad and GWT have built-in support for accessible UI elements. Google Web Toolkit implements more client-side functionality to obtain application behavior similar to desktop applications. WAI-ARIA is also supported in GWT. Now, prototypical implementation serves for detailed evaluation of model integration.

The mentioned technologies for implementation are typically Web-based. Thus, a good support is given for the integration of presentation modeling and implementation. Until now, automation systems with limited hardware resources may not support Web technologies for implementation. It is expected, that further development of technology will bring advances.

4 Conclusion and Outlook

The approach is focused on accessible Web applications and industrial automation systems. The majority of accessibility requirements are shared between these types of systems. Additionally, the usage of both systems is more and more merged in daily life use. Restrictions of user capabilities, technology or environment lead to similar requirements of product accessibility.

The approach examines the potential of UCD and MDD for accessible UIs. Model data describe much information which can be used to support AT with necessary data. Modeling includes static behaviors as site structure and navigation links. UML is used for graphical notation. Model-driven design supports the design of complex applications since particular aspects of structure and functionality are described in separate models. The integration of accessibility requirements in the process of development may help in future to integrate in and approach the knowledge of accessibility experts and software designers for the easier design of accessible UIs.

Until now, model data are translated manually into the runtime markup. Further work is necessary on accessibility-supporting model transformations as well as the design and implementation of a model compiler to support process automation.

Further on, the graphical UML-based notation of UI models is not naturally accessible. Text-based modeling notation e.g. Human-usable Textual Notation (HUTN) [Obj04] can avoid this problem but still needs adaption to the UML metamodel.

The presented basic ideas are as well plausible for other platforms e.g. Desktop applications or for another user group e.g. elderly people. Further research may show that accessible Web and Desktop applications can be designed with one unifying approach and implemented with integrative technologies as Adobe Flex or Microsoft Silverlight.

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User Interface Modeling for Accessible Web Applications with the Unified Modeling Language

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Abstract The design of accessible Web user interfaces (UIs) is a complex challenge for software architects and developers since the requirements are often respected too late in the development process. UI modeling allows research on particular aspects of accessibility requirements during the development process – especially during analysis and design. It is based on the description of user's workflow. Essential UI models are described. With *Model-driven Design* (MDD) and the *Unified Modeling Language* (UML) common standards of software engineering are used. In summary, the integration of accessibility in UI modeling helps to understand the needs during earlier development phases of software applications better.

Key words: Accessibility, User-Centered Design, User Interface Modeling, Model-Driven Design

1 Introduction

Despite accessibility guidelines for Web and software development exist since more than one decade; they do not meet practical needs of developers and designers in early project phases. According to e.g. DIN 15226 (DIN – German Institute for Standardization), the development process has four main phases analysis, design, realization and test (see Fig. 1). Typically, users are being mainly considered only during analysis. Afterwards, the user is not in the focus of attention. User-centered design (UCD) [fS] aims to overcome this developer-user gap of classical software development and to ameliorate the usability of software and Web applications. Even, this gap is seen by many experts as a major cause for the lack of accessibility in UI design. Additionally, existing accessibility guidelines address typically concrete

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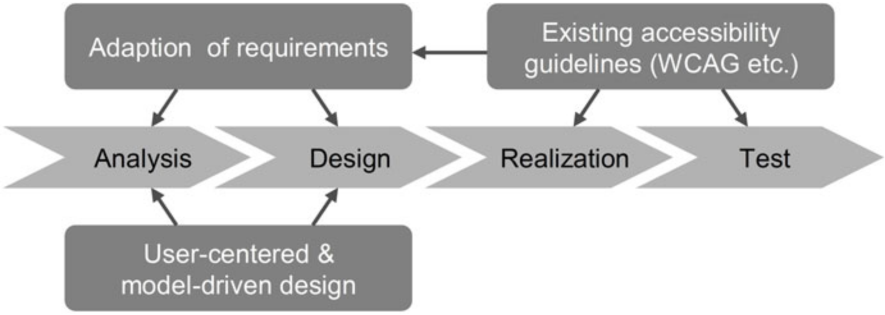

Fig. 1 Accessibility and development process

UI implementation and testing (e.g. [W3C08]) but not analysis and design. User-centered design is recommended but not detailed in appliance.

The UCD approach engages to-be users in design and conception of applications. UI requirements are integrated early in the development process respecting the growing influence of usability in product design. Even, UCD has advantages for UI accessibility if users with disabilities are included in conception and design of applications. Accessibility has impact on the whole application architecture including database design. Therefore, early integration in application architecture avoids late changes and additional costs for development. This paper is focused on the integration of accessibility requirements in UCD and model-driven UI design. Methods of user- and usage-oriented analysis are combined with model-driven design to examine the potential for engineering of accessible UIs. The UI modeling allows the description of single aspects in design as workflow, navigation or UI behavior. Research issues are:

- Influence of accessibility requirements on early UI design and conception
- Conception of the UI design process itself to facilitate the integration of accessibility requirements in software development
- Integration of expert knowledge about accessibility in design and modeling.

The modeling of a portal for travel information serves as a demonstration example. The integrative application combines interests of people with and without disabilities to gain more information about travel destinations and connections. The next section gives a short overview for the state-of-art in UI modeling. Then, the approach is demonstrated with the basic models for UI conception and an example. Finally, conclusions and an outlook are given.

2 Related Research

Publications for UI modeling can be separated into technical focused approaches as *User Interface Markup Language* (UIML) [200b], *User Interface Description Language* (UIDL) [200a], *Extensible Application Markup Language* (XAML) and analytical approaches as *User Interface Extensible Markup Language* (UsiXML), *Useware Markup Language* (useML) [Reu03], UMLi, *Task Modeling Language* (TaskML) and *Dialog Modeling Language* (DiaMODL). Technical approaches are focused on a platform-independent, abstract notation of UI components and structure which is independent from other components of the application. UsiXML as an analytical approach is more abstract and includes a metamodel for all UI aspects as navigation, domain or resources modeling. This may be more powerful in future but until now only few applications exist and a formalized modeling process is missing. Publications on model-based design of UIs as useML, UMLi, TaskML and DiaMODL include the process of modeling as well. New technologies as Silverlight, Flex or JavaFX enable to separate designer's UI layout from developer's core functionalities. Even, Web- and Desktop-based applications are merged on one technical platform. Only few publications exist for integration of accessibility in model-driven design [YHGS04, GKJ+08, JPV08]. The Dante-approach [YHGS04] allows semantic annotation of Web pages in a Web engineering process to provide navigation and to support screen readers to facilitate the audio presentation of the content. It is approximated that 85 % of the annotations can be provided by models.

3 Accessibility Requirements in Design Process

The Web Content Accessibility Guidelines (WCAG) [W3C08] of the W3-consortium describe the requirements for accessible Web applications. The four basic principles require that information is perceivable, operable, understandable and robust. They are not focused on the development process itself nor do they describe the requirements in early development phases as analysis or design. One basic idea of the guidelines is annotation of text-based information for all non-text content (captions, descriptions, subtitles, attributes, meta-information etc.). The Web Accessibility Initiative-Accessible Rich Internet Applications (WAI-ARIA) [W3C09] extends the WCAG concept with the requirements for accessible interface components in Rich Internet Applications (RIAs). WAI-ARIA is using additional attributes for roles, states and properties to describe UI element functionality and behavior. Besides the access to the main content, the application must provide access to navigation and functionalities for orientation and overview as breadcrumbs, sitemaps etc. to enable and facilitate the usage of the UI. Thus, some general accessibility requirements with influence on the overall design are:

- Additional text-based annotations for interface components, interface structure etc. (WCAG). This may affect e.g. the database design.
- Interface components communicate role, state and state changing (WAI-ARIA). Especially, this has importance for RIAs but only relevant information should be communicated to avoid information overkill.
- Serial order of interface components corresponds with user's workflow to support *Assistive Technology* (AT) as screen readers etc. Modern layout technologies as *Cascading Style Sheets* (CSS) allow a free composition of UI components but

are not used by AT. Therefore, the order of UI components must correspond with the workflow.
- Clearly structured navigation through the UI – every HTML page has one main modus (one focused activity) in the main content area. Especially for users with AT it is more difficult to gain and keep overview and orientation. Clearly declared activities facilitate the usage. Complex nesting has to be avoided.

Model-driven development is well-suited to integrate the first two needs into the design process since semantic annotations can often be taken from models and their behavior as well. Navigation modeling has to be focused on modes of usage and clearly structured navigation. UI models should describe workflow, UI structure, navigation, roles, behavior and states of components. User-centered design helps to identify workflows. Task modeling supports the serializing of workflow within the UI and clarifies the information the user need to control the application. Even, modes can be identified to describe the navigation.

4 The Modeling Concept

4.1 The Basic Concept

User interface modeling as part of the design phase serves to design the Human-computer interaction (HCI) of a software application with the user. Particular models describe different views on the HCI as navigation, abstract presentation etc. Three essential models are common for most existing approaches [Luy04] (see Fig. 2):

- Task Model: Describes user activities as actions and modes of usage
- Dialog Model: Describes the interaction of the user and the UI
- Presentation Model: Describes the UI structure and components and their behavior.

The UI metamodel combines these different views on the HCI. It may contain further models to describe user profiles or application resources. The UI modeling is part of a development process. Here, the process is limited to software design and development – in particular Web applications. Table 1 shows the integration of UI modeling in a UCD process. The UI modeling needs particular preparations as the workflow analysis in order to meet users' expectation with the task model. Analysis includes user's requirements and mental models of workflow. Task modeling includes typical use cases and activity diagrams. For graphical model notation the *Unified Modeling Language 2* (UML) [OMG09] is used. Since graphical notation is not accessible for visually impaired users, text-based notation with *Human Usable Textual Notation* (HUTN) [Gro04] completes the UML diagrams. UML 2 and HUTN are based on the same metamodel *Meta Object Facility* (MOF) [Gro] and have the same descriptive fullness.

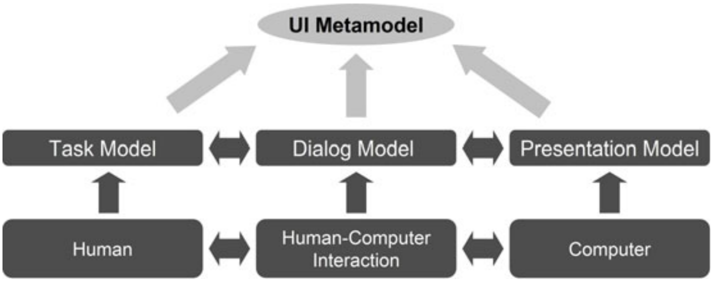

Fig. 2 Essential models in HCI

Even, an active participation of users with disabilities helps to integrate their needs in conception and design since the existing recommendations and guidelines do not covering all aspects of accessibility. After the conception, the models are used for the implementation with a Web application framework including accessible UI components. Software development starts with requirements gathering. Interviews with experts and users give a first overview for the functionalities and design objectives. Sometimes it may be difficult for users to describe their needs or problems with existing Web applications. Methodologies as Appreciative Inquiry enable detailed analysis with user integration [GLdL09]. Even, accessibility requirements may differ and be antagonistic between particular user groups as visually or hearing impaired people. Thus, requirements' gathering has to specify the user group at first.

Table 1 Development process and accesibility requirements

Development phases	User- and model-centered design process for UIs	Accessibility requirements	Methods
Analysis	Requirements gathering	Particular interests of all users	Appreciative Inquiry
	Workflow analysis	Workflow analysis and mode identification	Structuring maps, interviews, participant observation
Design	Task modeling	Relevant information	Interaction & usability pattern
	Dialog modeling	Clear navigation, serial order, multimodality	Participant observation
	Presentation modeling	Text-based annotations, enriched UI components	Prototyping, UI prototype evaluation
Realization	Implementation	Event-driven programming, international & national accessibility guidelines & recommendations	Prototyping, UI prototype evaluation, Web framework-based programming
Test	Test	Accessibility Guidelines	Automatic validation, heuristic evaluation, user tests

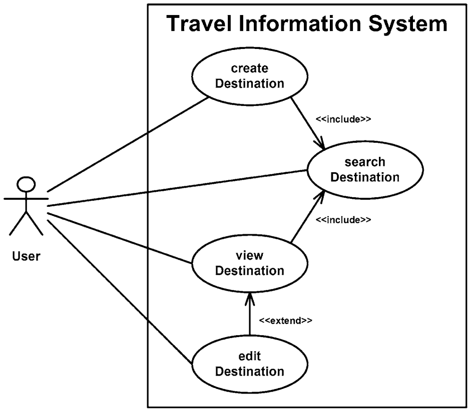

Fig. 3 Use case diagram for TIS

4.2 The Travel Information System Example

The travel information system (TIS) provides users with additional information about travel destinations, connections and tourist services and is used as a case study. Similar to a wiki, users can read, create and edit articles for particular travel destinations and generate the content of the platform by their self. Thus, typical use cases are search a destination as well as read, create and edit an article for a destination (see Fig. 3).

Different users were interviewed to obtain the needs of people with and without disabilities – particular visually impaired people. For people with disabilities particular demands were found:

- Information about hazard areas (e.g. cliffy areas in nature)
- Information about parking places, additional assistive offers, restrooms etc.

The next step in preparation is analysis of user's workflow for the documented use cases to support later on the task modeling. Structuring technique, participant observation and structured interviews are some techniques which support the analysis of user's mental model of workflow.

4.3 Task Modeling

The UI design starts with the description of user's workflow – the task modeling. The use cases (see Fig. 3) are detailed with UML activity diagrams. UML has different categories for work packages as use cases, activities and actions [OMG09]. Use cases define a global objective, intention and purpose of work and are described in use case diagrams. They consist of activities and actions which are described in

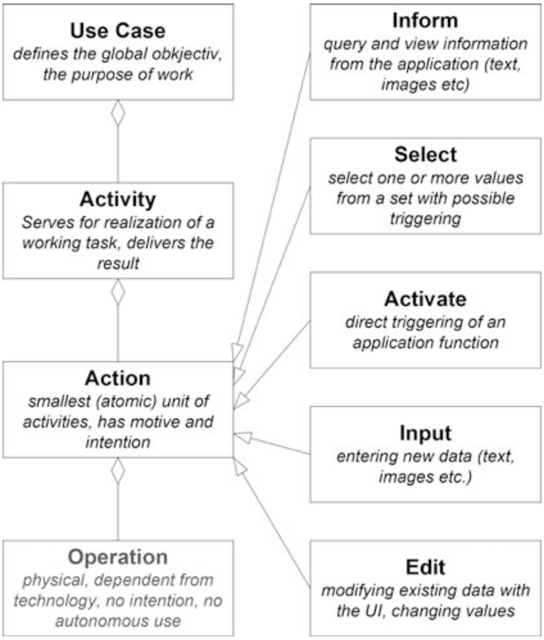

Fig. 4 Task hierarchy in UML 2 [OMG09] and basic actions in task modeling [Reu03]

activity diagrams. Activities include sequences of actions. Figure 4 shows the hierarchy of categories on the left side.

The physical operations of user's workflow as press a key or view an image are on the lowest level and not part of task modeling to stay independent from input or output modality. Here, user's actions are described with five predefined basic elements to facilitate the task modeling and to clarify the level of description. The five elementary use objects are *inform*, *select*, *input*, *edit* and *activate* (see Fig. 4 right side) [Reu03]. Basic actions represent mini-dialogs between user and UI as well and can be detailed with sequence diagrams in UML. Workflow of different people may differ and the UI should support various styles of workflow. Best practices of usability are also an appropriate source for workflow modeling to meet user's expectations. Accessibility requirements in task modeling are the device-independent description of user actions. Later on, the task modeling serves to determine all relevant information in the UI. Relevant is information when needed by the user to follow his/her intended work-flow. Figure 5 shows the activity diagram for the case study. The basic actions (inform, input, edit, select and activate) are described with UML stereotypes. Actions which are enabled at the same time are grouped in four activity regions (home, list, article, editor). The activity regions present the main modes [Thi10] of the TIS-UI. A mode is a particular context of an activity as edit a text or a search. The UI may have various states within the same mode. Later on, modes are mapped on single HTML pages in Web applica-

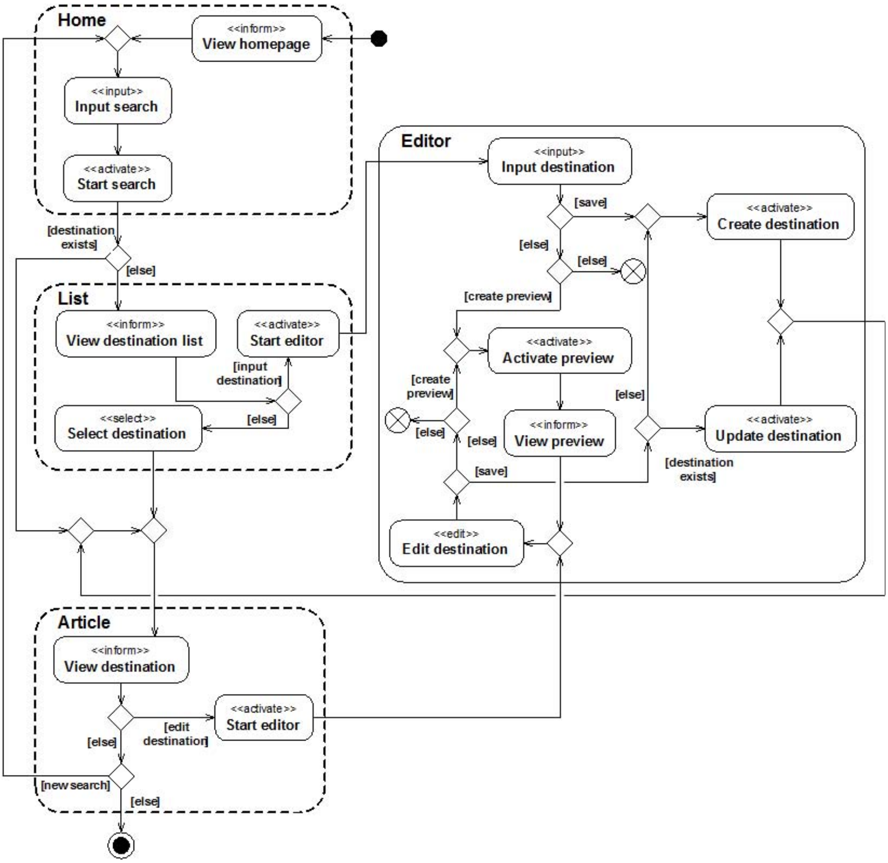

Fig. 5 Task model for TIS

tions. They may have submodes e.g. for auxiliary functions or navigation. Only one main mode is mapped to one HTML page to facilitate user interaction with assistive technology e.g. screen readers. Deep hierarchy of modes is avoided by the same reason. Next is the modeling of the (macro)navigation between particular modes of the application usage by the user. Main and submodes are identified from the task model and described with a particular activity diagram – the navigation model. Figure 6 shows the navigation diagram for the TIS. *Home*, *list*, *view destination* and *editor* article are main modes whereas *search* and *preview* are submodes and included in other modes. On the right side three (sub)modes represent additional UI functionalities for accessibility as a sitemap and an accessible main and utility navigation. They are not only related to another particular mode since they are always included as submodes and the sitemap can be activated from every other mode.

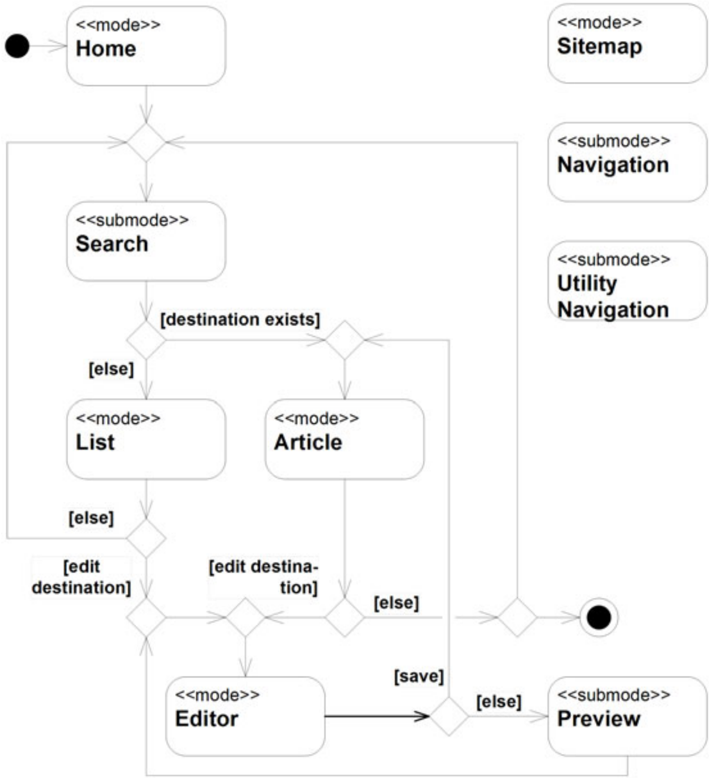

Fig. 6 Navigation model for TIS

4.4 Dialog Modeling

The dialog model describes the HCI and mediates between task model and presentation model [Luy04]. Task and navigation model describe user's point of view on HCI. In general, state chart are well-suited to design the UI behavior. Three methods are possible to derive the "other side" – the dialog behavior of the UI and to complete dialog modeling:

- Activity chain extraction [Luy04]: An Activity Chain specifies a path of different dialogs to reach a certain goal. A dialog represents a set of enabled actions and an activity chain can be described as a *State Transition Network* (STN). Notation is supported by UML state charts.
- Mirroring of user actions in the task model: An UML activity diagram is used for the notation of the task model. Further on, swim lanes in the diagram can be used to mirror the user actions into the UI and to describe the UI actions. Later on, UI actions can be separated from system core actions with an additional swim lane. State charts are used to detail the UI behavior.

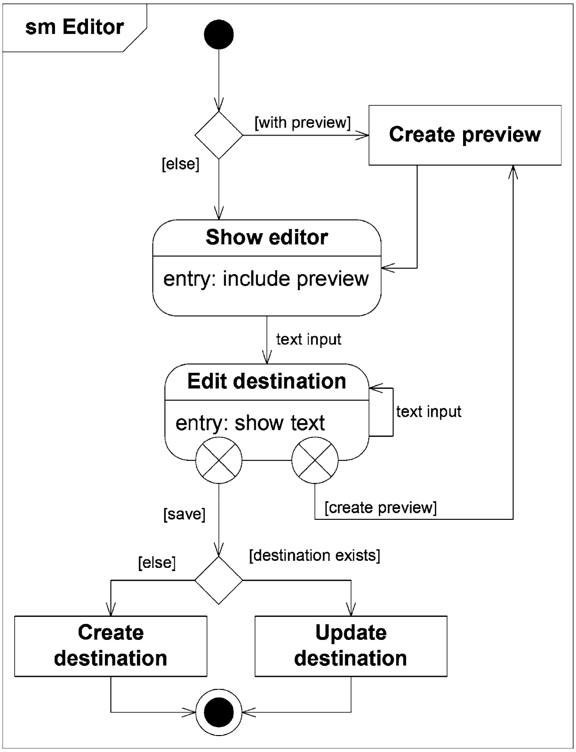

Fig. 7 State chart for the TIS editor mode

- State charts describing the UI behavior in a particular mode from the navigation model: The UI may have different states within the same mode. Figure 7 shows the state chart for the editor mode from navigation model (see Fig. 6). At first, the editor interface is shown. A preview for a document is included if existing. Then the editor waits for text input. The input is shown until the user activates the preview or saves the document. An existing document is updated. Otherwise a new document will be created.

4.5 Presentation Modeling

Presentation modeling includes the *Abstract Presentation Model* (APM). Modeling of accessible HCI dialogs can follow different strategies such as universal or multimodal design. Here, universal design is used meaning that perception and control of all relevant information in the UI is independent from in- or output device. Information is relevant if needed by the user to follow his/her intended workflow.

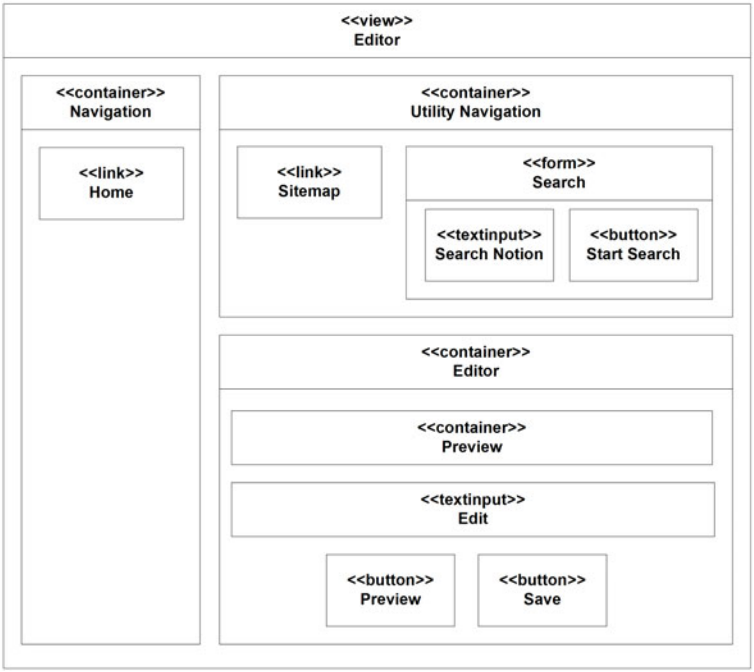

Fig. 8 Simple presentation model for TIS editor

Additionally, interaction and usability patterns can be integrated as best practices of interaction design. Modes from navigation model are mapped to single views. A view is restricted to contain only one mode and additionally some submodes to model site navigation, auxiliary functionalities such as search etc. This restriction supports accessibility since usage and orientation is easier with screen readers. The hierarchy of UI components is described with a class diagram. Figure 8 shows a simple class diagram of the abstract presentation model of the TIS editor including navigation, search functionality and the editor part with a preview if necessary. It shows the static hierarchy of site components.

Views and UI components have attributes which are mapped to HTML elements and attributes later on to describe metadata and device-independent properties. Device-independent event-handler and WAI-ARIA-like elements are used to describe the behavior of the UI during runtime. Abstract UI components are anchor, link, text, buttons, image, text input, choice and container. Attributes are used to declare necessary metadata for UI elements such as title, name, type etc. The root component is the view-element.

4.6 Implementation

The *Model-View-Control* (MVC) architecture pattern separates database design (model) from control and UI (view). The separation of UI and application design is well-suited to implement the user-driven models for the UI. Meanwhile, frameworks for Web application development support the usage of accessible UI components. Here, Java Web frameworks with MVC architecture are evaluated – e.g. the *Apache MyFaces* (AMF) including Trinidad and Tobago subprojects and the *Google Web Toolkit* (GWT). AMF is an open source implementation of *Java Server Faces* (JSF). Concrete presentation modeling and application layout are not part of the modeling process. For the implementation of the declared models an existing Web framework is used. There are different Web frameworks which combine the MVC-architecture pattern with libraries of UI components. AMF Trinidad and GWT have built-in support for accessible UI elements. GWT implements more client-side functionality to obtain application behavior similar to desktop applications. WAI-ARIA is also supported in GWT. The navigation model (see Fig. 6) is used to generate the navigation configuration for the JSF application.

5 Conclusions and Outlook

The approach examines the potential of user-centered and model-driven design of accessible UIs. Model data describe much information which can be used to support assistive technology with necessary data. Modeling includes static behaviors as site structure and navigation links. UML is used for graphical notation completed with HUTN for accessible modeling. The approach is focused on Web applications. Nevertheless the basic ideas are valid for other platforms as well e.g. Desktop-application or UIs for automation systems. Generally, task-oriented analysis is limited to recurring workflow when user can imagine the task in detail. Highly creative tasks such as painting or composing music have often no typical recurring workflow. In these cases, it is hard for users to describe the mental model of the task. Until now, model data are translated manually into the runtime markup. Further work is necessary to design and implement a model compiler to automate the process. Further research questions are:

- Integration of accessible user-generated content
- Integration of visual and auditory media with XHTML+HTML, SVG or VoiceXML.

Model-driven design supports the design of complex applications since particular aspects of structure and functionality are described in separate models. The integration of accessibility requirements in the process of development may help in future to integrate in and approach the knowledge of accessibility exerts and software designers for the easier design of accessible UIs.

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A Concept for User-Centered Development of Accessible User Interfaces for Industrial Automation Systems and Web Applications

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Abstract The importance of industrial automation systems and Web applications, often in combination, has been a growing area during the past decades. They are becoming an inseparable part of our lives. Hence they must be accessible to all users. Often certain user groups are being neglected in the development of such systems. Therefore, a systematic concept is required to support the development of such systems. In this paper, we will present a concept, which is proposed in the context of an ongoing research project, addressing the accessibility problem of the user interface. Both, industrial automation systems and Web applications share similar accessibility requirements. Hence, our concept addresses both systems, while discussing the suited methods to effectively assess accessibility requirements.

Key words: Accessibility, User-Centered Design, User Interface Modeling, Model-Driven Development

1 Introduction

To overcome the problem of accessibility one can start with the development process or try to provide a run-time solution. Our concept focuses on the development process. Many critical decisions upon system structure are being already made in the early stages of development [LVA05]. Therefore, an early assessment is very reasonable.

Web-based applications are increasingly gaining importance in our lives for a wider range of users, including those with disabilities. Hence, they must be ac-

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cessible to all their users. To overcome such problems, a wide range of accessibility guidelines, e.g. WCAG 2.0, for Web applications have been created. Yet, they do not address the development process; a systematic approach for developing accessible Web applications is missing.

Similarly, industrial automation systems have become an inseparable part of our lives, e.g. ticket vending machines. With the phrase industrial automation systems we refer to product automation or technical devices [LG99]. The big competition and saturated market has forced the producers to try to gain a bigger market fraction by embedding more new functionalities into their industrial automation systems. Hence, usage of such systems is getting more complex. However, often certain user groups are being neglected in development of such systems. Lack of a systematic approach for directing the development and the diversity of industrial automation systems make assessing accessibility to them cumbersome [Nie04, PSS+08]. The existing solutions are very dependent on the underlying technologies. Hence, a generic development solution is still missing.

In the upcoming sections we will provide some basic methods, which are used in the proposed development concept for accessible user interfaces (UIs). Section 2 contains the state of the art. In Sect. 3 we will describe our concept and in Sect. 4 a conclusion will bring this paper to the end.

2 State of the Art

User-centered Development (UCD) is a possible approach to embed accessibility into the development process. It involves the end users in the development process. Here the development is done in several iterations, while in each iteration developers are being provided with the feedbacks of the users on using the under development system. The iterative nature of UCD offers parallel treatment of system design, definition of functionalities and UI design. Hence, an appropriate architecture pattern is required to support this parallelization. The basic idea is to separate UI layout and control from system core functionalities. This may be realized by different alternatives, including the separation of front- and backend, a client-server concept, the Model-View-Controller (MVC) architecture pattern, or three-tier architecture.

Furthermore, Model-driven Development (MDD) is among the important methods used in combination with UCD. Typically, UML-based methods are being employed by the developers for the purpose of modeling. However, modeling of accessibility requirements of UI acquires a strong focus on user activities, which is not trivial using standard UML. Furthermore, it must provide a possibility of modeling UI elements abstract enough to be independent of the underlying technology. The existing solutions for modeling UI can be grouped into two categories: 1) practical approaches, e.g. User Interface Markup Language (UIML) [UIM09], User Interface Description Language (UIDL) [UID08], or Extensible Application Markup Language (XAML) [Mic] and 2) analytical approaches, e.g. User Interface Extensible

Markup Language (UsiXML) [Usi10] or the Unified Modeling Language for Interactive Applications (UMLi) [dS02].

Practical approaches are relied on platform-independent development of UIs, using certain development tools. Recent implementations such as Microsoft Silverlight [Mac08] or Adobe Flex [Tap08] provide the separation of UI layout from UI behavior as well as from system core functionalities. Whereas, analytical approaches are more abstract and include a meta-model for all UI aspects, which describes UI structure, components, behavior, navigation, domain, and resource. However, the analytical approaches are still under research and there is lack of tools for actual development. The existing analytical approaches for the modeling of UIs, e.g. useML, UMLi [dS02], Task Modeling Language (TaskML) and Dialog Modeling Language (DiaMODL) integrate the requirements of the modeling process including analysis.

Few modeling solutions address complete and systematic integration of accessibility in model-driven design and more importantly in the development process [Nie04, JVP08].

3 A UCD-Based Concept to Develop Accessible UIs

Our concept combines UCD and MDD, since UCD is focused on user's requirements and modeling allows describing particular aspects and views on the UI as navigation, state or behavior. The combination of UCD and MDD allows a clear analysis and declaration of accessibility onto UI design. Later on, the Abstract Presentation Model (APM) provides a semantic description of UI navigation, views, structure, elements, their roles, states and behavior. Finally, existing development tools can be used to implement the UI. Moreover, our concept considers that MVC architecture pattern for modeling is used; the separation of presentation (view) and functionality (controller) allows focusing on the UI with little interference to the system logic.

The concept addresses UI accessibility problems of industrial automation systems and Web applications, where often some user groups have difficulties interacting with the system, e.g. the ticket vending machines, which are not applicable for those with visual impairment or cell phones. Furthermore, it covers both industrial automation systems and Web applications by defining a generic approach which is applicable to both fields and limiting the target system specifications to guidelines and recommendations.

Industrial automation systems and Web applications may have different accessibility requirements, as far as the technology is related. However, both have accessibility requirements, which rely on similar principles. Based on this principle, the concept tries to provide the developers with guidelines on what factors needs to be considered. For this purpose, a repository of static helps has been included in the concept. It contains e.g. accessibility guidelines. In the following sections different aspects of the proposed concept will be described.

3.1 Accessibility

Accessibility in UI design means free perception and control of all relevant information for all users, also for those with disabilities [Int99]. Here, the information refers to those being needed by the user to follow his intended workflow constituted by his activities, actions and their relations. Despite the importance of accessibility, it is still a big challenge integrating it to the industrial automation systems, due to numerous reasons. Some reasons are:

- Variety of the requirements of different user groups
- Limiting UI technologies e.g. cell phones with small GUIs
- Difference between developer's mindset with that of the user.

The existing accessibility solutions are focused on accessibility guidelines, e.g. on the Web Content Accessibility Guidelines (WCAG) [Wor08b]. They mostly aim at run-time behavior of the system, i.e. how the system should work but not how it should be developed. Additionally, they are specifically created for Web applications. As long as human interaction with UI is concerned, industrial automation systems have similar accessibility requirements as Web applications. Therefore, the guidelines can be adopted for industrial automation systems and UCD is a promising approach for the UI development of industrial automation systems, since both systems require similar accessibility requirements, regarding their UI. Moreover, industrial automation systems and Web applications are being often used in combination. Projects like W3C Mobile Web Best Practices 1.0 [Wor08a] have used such guidelines for industrial automation systems, e.g. to overcome the accessibility problems of the elderly using cell phones. In that example more than 70 % of the guidelines could be employed for the industrial automation system [Wor08a]. Hence, our concept uses WCAG as the basis for addressing the critical points regarding the accessibility.

3.2 Multimodality

Multimodal interaction offers users to use various interaction channels in interfacing with a system. It uses different senses of human being, e.g. hearing or sight, for input and output of data. A simple example for a multimodal interaction can occur in a navigation system in a car, which can be interfaced via touchpad or voice input. The goal of a multimodal interaction is to use optimally the users' capabilities, by considering extra senses of the human users in the human-computer interaction (HCI) [Sti09]. In comparison to traditional interfaces (single-modal) multimodal interaction allows users to communicate more naturally and interface with complex information with more freedom of expression [TR07]. In [Sti09] multimodality is considered as a combination of interface styles, which can be used to improve the individual components in isolation so that the combination works better. However, this has to be differentiated from instantiating several copies of a UI in systems like in Mac systems. The proposed concept uses the approach used in [Sti09] for parameterization of the interaction channel.

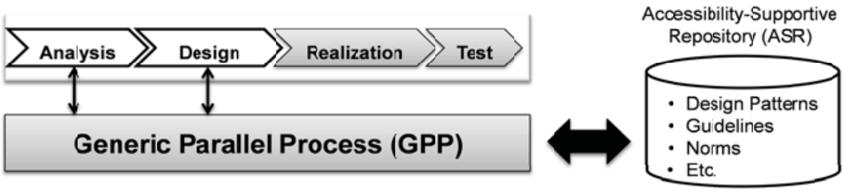

Fig. 1 An overview on the proposed concept

3.3 Methodology

The proposed concept consists of two parts; the *Generic Parallel Process* (GPP) and the *Accessibility-supportive Repository* (ASR) (see Fig. 1). GPP is a supportive process running in parallel to the typical development process. It helps developers to identify critical spots that are relevant to accessibility, during the analysis and design phase, as these two phases shape the basis of the under development system. GPP, then, provides the developers with tools and guidelines to take actions and assess the identified accessibility requirements. The identification and assessment of accessibility requirements are being supported by ASR, which is a predefined repository containing reusable components such as accessibility guidelines, design patterns and norms, which are generally necessary for an accessible UI.

3.4 Generic Parallel Process in Analysis Phase

In the analysis phase the requirements of the system are being collected. While in the traditional approach, a great focus on functional requirements is given, GPP tries to help developers identify accessibility requirements (none functional requirements). Besides methods like appreciative inquiry or structure laying technique, GPP investigates sight, hearing, motoric capabilities and knowledge (the 6th sense) of a user in the interaction with the systems [Sti09]. The aforementioned aspects can be affected in two ways: (1.) by user impediments, e.g. visual impairment, and/or (2.) external constraints, e.g. voice input in a noisy environment. Considering these aspects with the two affecting sources, the accessibility requirements can be analyzed. For example, Table 1 shows interaction aspects and constraints for a coffee dispenser and its process of maintenance.

Out of the information provided in Table 1, following accessibility requirements can be concluded.

a) Visual interaction with the system is possible.
b) Technical staff functionalities are required.
c) High contrast of the UI elements is required.
d) Voice input and output is not possible for the user.
e) Multimodal interaction is needed.

Table 1 Speculations of user impediments and his/her external constraints in the example of coffee dispenser

	Sight	Hearing	Motoric	Knowledge
User impediments	Very good	Very good	Very good	Technician
External constraints	High light intensity	Very noisy Environment	Back and front side of the machine must be accessed. Access at the same time needed.	n.a.

Another important step is to model with their correlations and conflicts. This will help identifying requirements that need to be eliminated or might be added to the requirements set. Currently, the concept assumes that this step of analyzing requirements is to be done by project managers or similar authorities.

For the purpose of modeling requirements, the *requirements graph* method presented in [LVA05] is used. This method is very suitable for the purpose of modeling none-functional requirements [LVA05]. It arranges requirements as graph nodes, connected to each other by labeled arcs. The labels are "hurt", "help", "make", or "brake", with "Hurt" referring to a conflict, "Make" to dependency, "Help" to recommendation, and "Hurt" to discouraging relation between the requirement nodes. The intensity of each relation can be defined using an intensity value from the set $I = \{--, -, 0, +, ++\}$, where "$--$" is the strongest negative and "$++$" is the most positive intensity value [LVA05].

3.5 Generic Parallel Process in Design Phase

In the design phase, the concept supports the developers to design the UI in parallel to the design of the system logic. It helps identifying critical points in the interaction that affect the accessibility. In this phase a scenario-based approach is being employed for designing the structure of the system. Once the scenarios are defined, all cases of the scenario are being modeled. The proposed concept employs a UML-based approach, since it is universally used, hence it can be easily used in parallel to designing the system logic. Furthermore, it is easily extendable using UML profiles. Focusing on the architecture pattern, workflow, and relevant information on the end users, three aspects of the interaction with UI is being modeled: task modeling, dialogue modeling, and presentation modeling. Despite existing methods, which are very much syntax based, the concept uses guidelines aimed at the aforementioned criteria for modeling the three aspects of interaction. The syntactical complications of modeling UI are being removed semantically. Figure 2 depicts the important guidelines for each criterion, used in the concept.

As it can be seen in Fig. 2, the knowledge about user's workflow is necessary to determine the relevant information on the end user, since it is only being considered in the usage context. The relevant information is being stored using a text

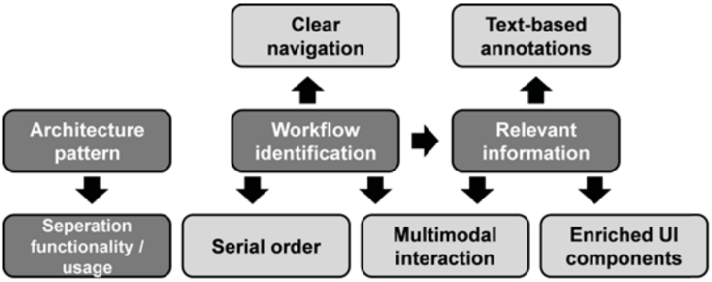

Fig. 2 The important guidelines for each criterion

based annotation such as XML. The separation of data model/core-functionality and UI-presentation/control enables multimodal concepts for usage and different layouts for particular input/output devices. Using a well-suited architecture pattern, e.g. MVC, this separation can be easily achieved. Furthermore, deployment of multimodal interactions is tightly dependent on knowing the workflow and the relevant information. Design of interface components in a serial order – corresponding to user's workflow – to support Assistive Technology (AT) such as screen readers and structuring the interface navigation distinctly and avoiding deep hierarchical structures, in order to support sitemaps and breadcrumbs for instance are further guidelines used to model UI. In Table 2 the sequence of UML diagrams, which should be implemented in each of the three aspects of interaction with UI are listed. The diagrams in each row should be considered together, while modeling.

3.6 Accessibility-supportive Repository

ASR feeds the GPP with design patterns, guidelines, norms and standards, which have been collected. Based on existing patterns, the concept includes a pattern structure as it can be seen in Fig. 3. The design pattern contains information on

Table 2 Overview of the UML diagrams in the GPP (AD – UML activity diagram, UD – use case diagram, CD – class diagram, SC – state chart)

Task modeling diagrams	Dialog modeling diagrams	Presentation modeling diagrams
Use case – UD Activities – AD	Modes, macro-navigation – AD	Views, main & utility navigation, sitemap – CD
Actions – AD Work objects (UI data) – AD	Interactors, Roles of UI components – CD	UI elements, attributes & behavior – CD
Workflow – AD	Micro-navigation (Sequences, alternatives), UI behavior – SC	Order of UI elements – CD

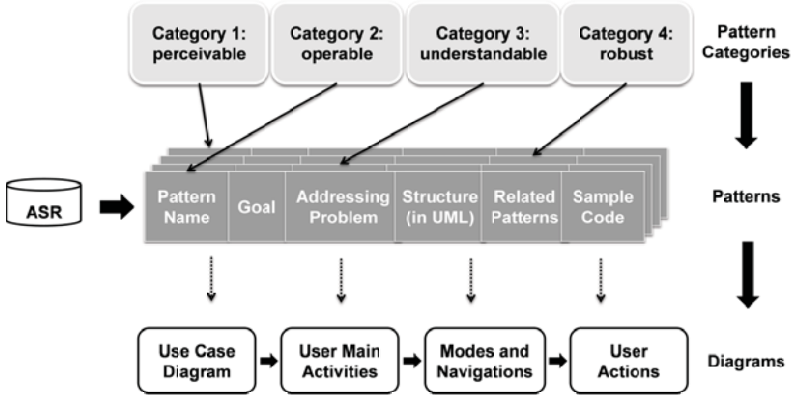

Fig. 3 Various categories of the accessibility patterns, their instances and derivation of design diagrams

the problem, usage context and solution, illustration, reference to other patterns or code/design idioms. Using the patterns developers can design each step more easily. The design patterns are based on a selection/adoption of WCAG 2.0 accessibility guidelines [Wor08b]. The patterns can be categorized into four categories: perceivable, operable, understandable and robust; each addressing a certain aspect of accessibility [Wor08b]. Figure 3 illustrates the various categories of the accessibility patterns and their connection to diagrams.

The UI of a coffee dispenser as a case study shows examples of the GPP analysis and design phase. Figure 4 shows the first step in analysis – the identification of user modes. Based on the use cases, main activities are detected. In the example of Fig. 4 three main activities "Change product", "View product", and "Search product" are detected. Correspondingly, the user workflow is grouped by modes of usage.

Figure 5 shows the main navigation network of modes drawn in dashed boxes. The relation of each node describes the possibilities of moving from one mode to another one. Here the technological description is not of interest. The selection of a drink, in this example, might be a simple read through the buttons on a coffee dispenser or a sound module reading out the available drinks.

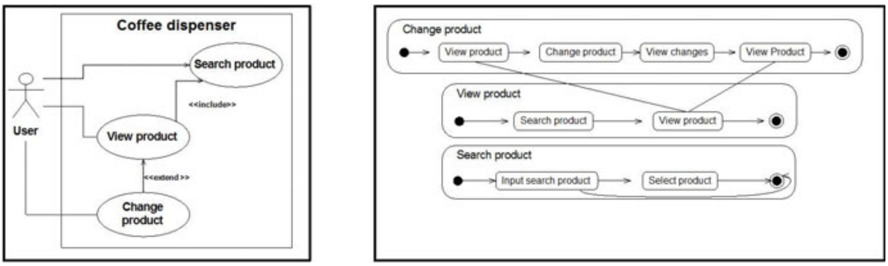

Fig. 4 Use cases and user main activities

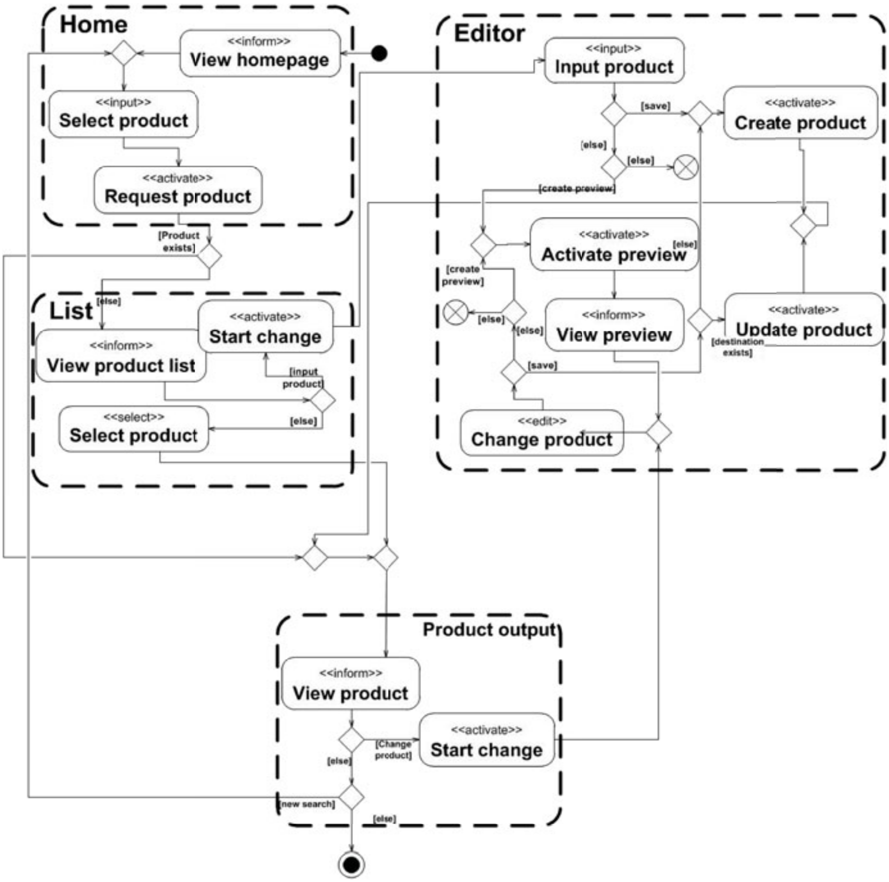

Fig. 5 UI main navigation modes and user's actions within each mode in the example of coffee dispenser

Furthermore, each navigation mode contains several actions. For instance, once the user has decided upon selecting his drink, might move to the corresponding navigation page. Then he can take several steps, i.e. actually selecting his desired drink, reviewing his selection or canceling it. Here, each mode itself is being refined by internal actions. The actions are based on atomic action categorization described in [Reu03]. The actions are defined as five stereotypes select, activate, inform, input, and edit. In the concept the two steps of defining mode navigation and user actions are being done using separate diagrams. In this paper, for more compactness we have shown both in one diagram, in Fig. 5.

4 Conclusion and Outlook

The proposed concept is based on the survey made on the state of the art and consists of a set of suitable methods. It provides a parallel process to the development process, while considering the end users.

We have discussed the potential of UCD and MDE in maintaining accessibility in developing UIs. Having focused on the early development stages, i.e. analysis and design phase, we have investigated suitable methods and technologies, which can assist developers by designing an accessible UI for industrial automation systems and Web applications.

The future work of our project is focused on an automated identification and analysis of the requirements, a systematic bridge between analysis and design phase, and an automated transformation of the detected diagrams.

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Part V

Semantic Networks and Ontologies for Complex Value Chains and Virtual Environments

A Multi Level Time Model for Interactive Multiple Dataset Visualization: The Dataset Sequencer

Thomas Beer, Gerrit Garbereder, Tobias Meisen, Rudolf Reinhard, Torsten Kuhlen

Abstract Integrative simulation methods are used in engineering sciences today for the modeling of complex phenomena that cannot be simulated or modeled using a single tool. For the analysis of result data appropriate multi dataset visualization tools are needed. The inherently strong relations between the single datasets that typically describe different aspects of a simulated process (e.g. phenomena taking place at different scales) demand for special interaction metaphors, allowing for an intuitive exploration of the simulated process. This work focuses on the temporal aspects of data exploration. A multi level time model and an appropriate interaction metaphor (the Dataset Sequencer) for the interactive arrangement of datasets in the time domain of the analysis space is described. It is usable for heterogeneous display systems ranging from standard desktop systems to immersive multi-display VR devices.

Key words: Virtual Production, Numerical Simulation, Data Integration, Visualization, Virtual Reality

1 Introduction

Simulations have become a common tool in many fields of engineering today. An integral part of computational simulations is a subsequent analysis process in order to verify the underlying simulation model or to make decisions based on the results of an efficient simulation. While complex phenomena in engineering sci-

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ences can seldom be described using a single model, different aspects are examined separately. In practice this was done with rather low coherence between the single simulation models in the past, omitting a lot of potential and accuracy caused by weak or neglected linkage between the simulation models. With the advent of integrative simulation approaches that connect simulation models at the data level to create contiguous representations of the simulated processes, the need for appropriate analysis tools arises.

A visualization of multiple datasets is often used to compare datasets to one another. Even more important this approach becomes for the exploration of complex phenomena that are not identifiable until multiple datasets are analyzed in a coherent view. For a multiple dataset visualization this demands for additional functionality in terms of interactivity as compared to traditional single dataset scenarios. The multiplicity of a multiple dataset visualization can be categorized into a horizontal and a vertical aspect [AHCP07], whereby the horizontal one addresses a temporal sequence of datasets and the vertical addresses different datasets describing the same time interval in different aspects (e.g. scales of scope). This work focuses on the interactive manipulation of the position of datasets on the horizontal axis as a means to explore the contiguous simulation results.

The remainder of this paper is organized as follows. Section 2 shortly explains the simulation platform developed to model and execute integrative simulations. Aspects regarding multi dataset visualization in contrast to single dataset visualizations are discussed in Sect. 3. Section 4 outlines the idea of a multi level time model and refers to appropriate related work. The interaction Sect. 5 introduces the *Dataset Sequencer* interaction metaphor built on top of the aforementioned model. Finally Sect. 6 concludes the work.

2 Integrative Simulation

In the domain of Materials Engineering, the idea of Integrated Computational Materials Processing (ICME) has evolved. It approaches the integration and interconnection of different material models [ABC06, Raj09]. Different aspects of material evolution throughout a production process are simulated at different scales. A simulation platform has been developed [BMR+11, CBKB08, SP09] that enables collaborative simulation, utilizing interconnected simulation models and hardware resources, based on a grid-like infrastructure [FK04]. A key aspect for the coupling of simulation models is the correct translation of data between the single simulation models. For this, a data integration component has been developed that uses domain ontologies to assure semantic correct data integration [MMSJ11]. Access to the simulation platform is given through a web-interface that allows for collaborative visual design of simulation workflows [BMR+11]. Beyond the integrated simulation itself, the analysis of integrated simulation results is an important aspect in order to gain knowledge and insight from those simulation efforts at all. The project concept of the simulation platform thus explicitly includes the aspect of visual data analysis.

For the analysis of the integrated processes, the visualization application has to deal with the multiplicity of datasets. Especially with the additional degrees of freedom in the interaction handling induced by it. In a pre-processing step each of the datasets is manually prepared and visualization primitives are extracted, i.e. the object's surface geometry or e.g. boundary edges of microstructural grains. In many cases domain specific knowledge is required in order to extract meaningful visualization primitives and thus this step cannot be automated completely yet. However, with the further development of the ontology based knowledge representation of the data integrator, some extraction cases could be automated in the future.

3 Multiple Dataset Visualization

The main characteristic that differs a multiple-dataset- compared to a single-dataset-analysis apparently is the common visualization context that needs to be established. At the technical level this imposes requirements for data management and interaction components that address this multiplicity.

Single datasets often exceed the available resources of a visualization system already. Even more does the integration of multiple datasets into a common visualization context. Thus, the incorporation of decimation techniques is mandatory. We have used different remeshing [VC04] and coarsening [SZL92] approaches for this to prepare multiple resolution levels of the visualization primitives. Different detail levels can be selected at the beginning of a visualization session, e.g. to adapt to the current system's resources. Future work will focus on dynamic selection strategies that automatically adapt temporal and geometrical detail levels to the analysis context (cf. Sect. 6) at runtime. A fundamental component for dealing with multiple datasets is a data structure that provides structural, topological and logical meta information at different levels of abstraction. On the lowest level the relations between files on disk and how they buildup the single datasets (spatial and temporal) has to be modeled. Especially the interaction components in the system have to account for the multiplicity of entities at runtime and thus more information is needed about the relations the datasets have in the visualization context (spatial, temporal and logical) between the multiple datasets. Some modules of the runtime system need even more, specific meta information like e.g. the connection between different color transfer functions (lookup tables) and the datasets referring to it. Based on the concept of role-objects [Fow07], the presented application provides a central data model to all of the different software modules the application consists of but at the same time maintains basic software engineering principles like high cohesion and loose coupling [SMC74]. Each module is able to augment it's view on the data structure with specific data without interfering with other modules or creating inter-dependencies as it would be the case with a naïve shared data structure implementation.

Most existing multi dataset visualizations use a multi-view approach, consisting of side-by-side contexts, arranged in a grid on the screen, with each cell containing a single dataset, e.g. [AHCP07, Kha09, BCC$^+$05]. Generic visualization tools like ParaView [Squ08] or EnSight [Com25] contain some functionality to work with multiple datasets in multiple views or even to merge a little number of datasets into one. Those are useful for a side-by-side comparison of two datasets, e.g. real data and simulation data (EnSight's "Cases" feature) or for the analysis of partitioned datasets. But those solutions do not contain features that assist in an interactive analysis of multiple contiguous but heterogeneous datasets that comprise a relation in the time domain. In contrast to these "multi-context" approaches, the presented solution uses a single context, which in turn can be extended to span multiple windows or displays. This makes it usable in multi-screen, and most prominently in immersive display systems, where the usage of multiple side-by-side contexts would disrupt the effect of immersion (cf. Sect. 5.1).

4 Multi Level Time Model

Time-variant data, which is the dominant kind of simulation results today, inherently contains a notion of time. When dealing with a single dataset in a visualization environment, the handling of spatial and temporal frames is conceptually not that critical. In practice both, spatial and temporal dimensions, are scaled to give a decent insight into the data, which could be interpreted as a normalization of the data presentation into the spatial and temporal attention span of the user and the display system he is using.

For a visualization of multiple datasets that have strong inter-relations, the spatial and temporal placement and the interactive manipulation of it have to be considered with much more attention. Although the spatial component in visualization and interaction is important, too, this work is focused on the temporal aspects. In the author's opinion, this aspect needs to be taken more into account for the complex visualization scenarios that are becoming more important today and probably will even more in the future. An example for this is the aforementioned domain of ICME that inherently needs to handle simulation data from different sources with heterogeneous temporal and spatial resolutions, modeling different aspects of material behavior during a production process [Raj09]. Other domains of simulation sciences are most likely facing the same problems with the growing number of integrative simulation approaches.

Handling the temporal relations between datasets in an interactive environment introduces an additional degree of freedom to the analysis space: while all time instants of a single time-varying dataset can be reached with a linear navigation on the time axis, this is not enough for the multiple dataset case. To provide a flexible analysis environment, the temporal relations between the datasets inside the analysis environment have to be handled dynamically. This means that beyond the time-navigation itself, the manipulation of the single datasets' placement on the timeline has to be considered as well, to allow for the interactive comparative analysis of temporally related datasets.

4.1 Related Work

The idea of a temporal hierarchy is known and used in the fields of 3D Animation and Motion Graphics. Also work in the field of real time graphics, like the X3D standard [ISO08] includes definitions of node types and so called *event routes* that could be utilized to process time information and thus to integrate a time hierarchy. But in the field of scientific visualization the notion of time is mostly limited to the mapping of discrete timesteps to a single linear time axis. Navigation metaphors stick to VCR-like controls, allowing only for linear navigation [BJ96] and not for further interaction with the time domain. Though, for single-dataset visualization, this apparently is sufficient.

For exploratory analysis of multiple time-varying datasets the notion of a temporal hierarchy becomes important. Aoyama et al. [AHCP07] have proposed an application named *TimeLine* which includes – as the name suggests – a timeline view containing thumbnails for multiple data sources the visualization is using currently. But there is no interaction happening with neither the timeline visualization nor regarding temporal relations between the single data sources in general. The work from Khanduja [Kha09] concentrates on Multi Dataset Visualization, focusing on interactive comparison of volume data, and addresses several aspects arising from this in comparison to single-dataset visualization. Temporal data coherence between timesteps in different datasets is exploited to reduce the runtime data load, but neither the temporal relation between the datasets nor any interaction in the time domain is taking place in his work. Wolter et al. [WAH+09] have proposed an abstract time model that describes the mapping between discrete time steps of simulation data and continuous time values, representing different aspects of time: *discrete time steps* represent a single time instant of the simulation. The *simulation time* refers to the time that a timestep represents in the original simulation's time frame. The *visualization time* normalizes the duration of the dataset into the interval [0..1]. The *user time* relates to the real-world time a user is acting in while viewing and navigating through an interactive visualization. While this time model fits very well for the handling of arbitrarily sampled datasets, this view is too granular from the viewpoint of handing multiple dataset in a dynamic fashion. The relation between multiple datasets is described in the continuous time domain and does not directly refer to the discretization of timesteps in each single dataset. A simple example clarifies the problem: If a dataset is moved on the time axis beyond the current boundaries of the overall visualization time, the normalized mappings of time values to all of the discrete timesteps of the overall simulation would have to be recalculated. The relative position of all discrete timesteps in relation to the overall timespan of the analysis context changes in that moment. For the static arrangement of multiple datasets this model is suitable, however for dynamic behaviour at runtime, additional work is needed.

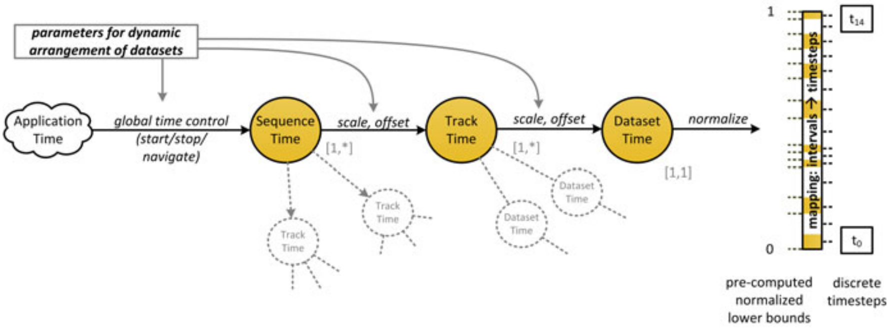


Fig. 1 Multi-Level Time Model: The application timestamp is dynamically transformed into the local normalized *visualization time* which then is mapped to the appropriate timestep using a pre-computed index structure

4.2 Multi Level Approach and Runtime Time Model

The proposed solution for enabling a dynamic handling of temporal relations consists in building a hierarchy of multiple local time models as they were proposed by Wolter et al. [WAH+09]. Each single dataset's internal discretization issues are encapsulated by this very well, allowing to control each one by the normalized *visualization time*. The temporal relation between the datasets (i.e. their local time models) and the global timeline in which those are embedded can then be modeled as a graph, describing how the incoming global time needs to be transformed in order to make each dataset aware of its current normalized visualization time. Transformations that are needed to place each dataset in the temporal hierarchy can be reduced to *offset* and *scale*.

The meta information model includes an hierarchical representation of the data. From this, a directed acyclic graph of time-transformation nodes is built (cf. Fig. 1). During the update traversal of the application's event loop, this graph is propagated with the application timestamp which is then transformed through three levels (sequence, track, dataset, cf. Sect. 5) before the local time-models are reached. At this point the time value has transformed into the local normalized relative *visualization time*. The mapping of normalized time intervals to the discrete timesteps of the datasets is handled by each dataset's local time model [WAH+09].

An index structure is pre-computed that maps *visualization time* intervals to the appropriate timesteps. Finding the current timestep, i.e. the interval that contains the incoming time value, thus is realized by a lower bound query to that index structure. Sequential access is further accelerated by caching the last query result as the starting point for the subsequent query. Hence the additional runtime overhead caused by the multi level approach is negligible compared to a fixed arrangement of multiple datasets in the global temporal context. The graph needed to achieve the dynamic arrangement of datasets at runtime is very small as it only involves the datasets as a whole, not each single timestep.

5 Interaction – The Dataset Sequencer

The basic idea of an integrated process visualization is to provide the user with an environment for the analysis of the relations between the different process steps. Compared to the large number of work that can be found for interaction in the spatial domain, less approaches are known for the definition of temporal relations and appropriate interaction methods and no methodology for this has been widely adopted yet in the field of data visualization. While interaction metaphors for the spatial domain can be derived from real-world behavior, e.g. drag-and-drop interaction, an appropriately intuitive real-world paradigm is not available for the manipulation of temporal relations. Thus, for interaction in the time domain, more abstract interaction metaphors have to be developed. The interaction tasks for the integrative multi dataset visualization can be separated into navigation and manipulation, just like spatially characterized interaction tasks [BKLP04]. For the navigation, VCR-like controls are widely used (e.g. ParaView [Squ08]) that allow for a linear navigation in the temporal dimension [BJ96]. Interactive control over the inter-relations of the single datasets, i.e. the sub-aspects of the simulated higher-level process, in the time domain, can be categorized as a manipulation task: it changes the relation of the dataset to the global time axis and to other datasets in the visualization context. This allows to arrange for side-by-side comparisons of similar sub-processes (horizontal axis), e.g. material's behavior in a heating process, before and after a machining process that may change the material's behavior in the subsequent heating process. As multiple datasets at different scales may be involved, special care has to be taken to the temporal integrity of the displayed data. Datasets representing the same time intervals have to be consistently aligned in the time domain (interlock on the vertical axis). If this constraint is violated, an inconsistent and simply wrong visualization state occurs that could induce an incorrect mental map [MELS95] of the visualized data to the user, invalidating the whole analysis process in the worst case.

In the field of audio and video production, clip-based editing and organization of audio/video events on multiple parallel timelines is a common approach, e.g. with digital audio workstations like *Cubase*[1] these concepts have matured since the late 1980ies. Our approach tries to utilize akin interaction and 2D visualization methods for the interactive placement of datasets on multiple tracks embedded into a global timeline. The idea of using such an interaction metaphor as a means for real time interaction with a multi-dataset visualization is – to the best of our knowledge – a new approach.

Figure 2 shows an integrated visualization scene and a first prototype of the presented Dataset Sequencer 2D interface. On a global horizontal timeline the datasets are represented as rectangles extending the time interval they are active in. Multiple *tracks* are stacked vertically to place concurrent datasets, e.g. representing micro- and macro-structural simulations. The temporal position of a datasets in the overall context thus can be intuitively depicted an manipulated by drag-and-drop interaction. Additional hints, like the original alignment of datasets, help the user to keep

[1] Steinberg Media Technologies GmbH

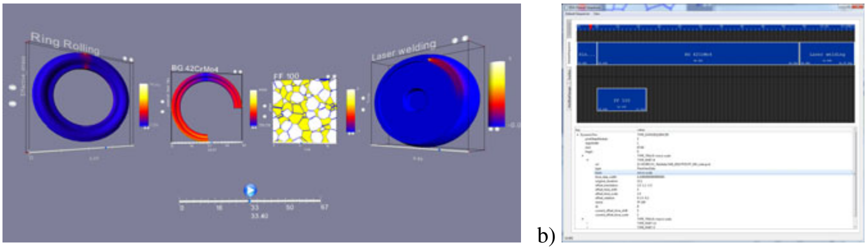
a) b)


Fig. 2 **a** 3D Visualiaztion **b** 2D User-Interface of the Dataset Sequencer

track of the original context. Additional meta information about the datasets can be queried and manipulated inside the 2D interface (lower part). This allows for exact setting of e.g. the *scale* and *offset* values or direct entry of begin/duration values for a dataset. The initial configuration and the logical relations and grouping information is stored in the aforementioned meta data structure. Explicit begin time values as well as scale-factors and offset values (temporal as well as spatial) can be used for the description of the initial setting. Another option allows for an automatic alignment for the initial setup that simply queues each new dataset to the end of the track it has been selected for.

5.1 Hybrid 2D/3D Interaction

The presented visualization application is targeted to drive heterogeneous display types, e.g. using head-tracked stereo rendering and immersive input devices as well as standard desktop workstations or notebooks. For the navigation tasks VCR-like time-slider controls are embedded into the 3D visualization context (cf. Fig. 1). Each dataset has a time-slider attached that scrolls through it's timesteps. The thereby selected timestep is displayed as long as the slider is grabbed or when the global time control is paused. An additional free-floating time-slider controls the global time. This approach works well for navigation tasks in the time domain. Approaches to use the sliders for the manipulation of the temporal relations turned out to be useless as no valuable feedback could be provided to represent the influence of the interactive manipulation to the global relations instantly. Additional graphical objects in the scene could be used for this, but as the multiple datasets already occupy the visualization space and additional objects just would clutter up the scene, this approach was not further pursued. Thus this task was split off into the more abstract 2D Dataset Sequencer GUI.

The target display systems for the multiple dataset visualization application are heterogeneous, thus the 2D interface and the core application communicate over a network interface, utilizing the aforementioned (cf. Sect. 3) meta data structure. Depending on the target display system, the Dataset Sequencer GUI can be used in a windowed application side-by-side to the 3D Context on a desktop machine, or on a separate, "control panel" like machine, e.g. in front of a power wall, or on a tablet device literally inside a fully immersive CAVE-like environment.

6 Conclusion and Future Work

We have presented interaction methods for the handling of multi dataset visualizations. Focusing on the temporal aspect of an integrative visualization context, a multi level time model has been presented. A hybrid interaction metaphor for the navigation and manipulation in the temporal dimension suitable for heterogeneous display system architectures has been developed that utilizes 2D and 3D interaction metaphors. The 2D interaction metaphors are based on non-linear editing concepts found in media production industry but utilizing this concept for interaction with a real time visualization application depicts a new approach in the field of data visualization. The aim of the Dataset Sequencer UI however is not to resemble all the high-sophisticated editing capabilities of audio or video production systems, but to develop interaction methods that ease and assist the analysis process in a multiple dataset visualization environment, inspired by these editing techniques.

The main focus of future work will concentrate on the data handling problem residing in the handling of multiple datasets. Considering the temporal and geometrical resolution of the involved datasets as well as data-driven importance metrics and available system resources, heuristic detail selection methods will be researched. Those will provide context sensitive behavior of a dynamic detail selection framework. Other aspects include the refinement of the 2D user interface, for example automatic alignment and vertical interlocking of datasets in the timeline will be improved. The incorporation of data plots into the sequencer view will provide the analyst with more guiding information allowing for easier orientation in the integrated environment of the datasets. In the other direction, user-drawn graphs, sketched within the 2D interface, could be used as an importance metric for the detail selection methods.

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Platform for Integrative Simulation

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Abstract The use of simulation tools in production process planning within industrial environments is already well established. However, this generally involves conducting individual simulations of specific sub-processes using default settings as the boundary parameters. This method does not take into account production history influences on the individual sub-processes. In order to improve planning quality using simulations, the individual simulations need to be linked to form a continuous simulation chain. The methodology for linking simulations described in this paper allows flexible extension of the overall system, allowing incorporation of a variety of heterogeneous simulation chains. In addition to linking distributed simulation resources on an infrastructural level, Internetbased access is also provided, which allows partners to collaborate in setting up simulation chains. There is a data integration component to ensure the correct syntactic, structural and semantic transformation of data between the individual heterogeneous simulations and to ensure all the required simulation data is integrated into a common database. To enable integrative analysis of the simulation data for a whole process, there is an interactive visualisation component which can be used on a variety of visualisation systems, from regular workstation computers through to dedicated virtual reality systems with numerous projection surfaces. Interactive modification of dataset timing within the context of analysis is a key aspect in this respect. In future, the system will be expanded so that interactive analyses can be conducted on the in-tegrated database and bidirectionally coupled with the visualisation component in real time. This will enable intuitive

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access to the integrated simulation data, even across process boundaries, thus providing optimal support for planning or modification of production processes.

Key words: Production Technology, Simulation, Interoperability

1 State of the Art

The need to couple and automate simulation rather than manually drive them is obvious: ac-cording to a study conducted by Lang in 2003, the process development time using manually linked simulations incurs an overhead of 60 %, caused solely by manual operation of the individual simulation components and conversion tools of a simulation chain. Hence optimising the links between simulation tools offers huge potential to save on planning costs with respect to simulating aspects of production, i.e. the domain of virtual production. Since numerous studies have highlighted this issue, it begs the question as to why such auto-mated environments are not found in practice. Our opinion is that many approaches fail due a lack of flexibility and, consequently, a lack of user acceptance. The often relatively inflexible facilities for coupling just a few selected simulation tools may be the reason behind this. Coupling is limited to the facilities offered by the manufacturers, which in turn are generally limited to the existing tools of the one manufacturer. This severely limits the choice of simulation tools that can be linked and, therefore, the simulation scenarios that can be mapped. Thus at present there is no universal solution to the problem of simulation coupling. In essence, there are three broad areas that must be taken into account when coupling simulations:

- The technical level – infrastructure, data exchange
- The data level – syntax, structure and semantics of the data formats and models
- The analysis level – analysis and evaluation of the simulation results from linked simulation results.

On the technical level, simulation tools are special software components that run on corre-sponding hardware resources. Accordingly, any technical solutions for linking simulations must take into account both components, i.e. the software and the hardware. The solution for coupling on a technical level is discussed below.

1.1 Grid Computing (Technical Level)

Grid computing, which emerged in the mid-1990s, could help meet the aforementioned challenge on a technical level. Using grid computing, many national and international projects seek to combine computing resources and provide uniform access to them [BKS05]. Thanks in particular to the rapid proliferation and expansion of the Internet, basic networking of resources is not a problem in terms of infrastructure. However, since the early days of computer technology, the coupling of software components in distributed systems has always posed a challenge. As in all other areas of computer science, ever higher levels of abstraction are being created here too, while concepts and approaches are becoming more generic and can therefore be used in an ever-widening range of applications. Starting with remote procedure calls (RPC) [Sri, RG04], the Common Object Request Broker Architecture (CORBA®) [Hen08, OMG], web services and concepts like service-oriented architectures (SOA) [Nat03] or ones specific to grid computing such as the open grid services architecture (OGSA) [FKSe05], there are currently a number of different concepts at various levels of abstraction for creating a distributed software architecture. Hence the whole area of "simulation coupling" presents a very heterogeneous landscape of concepts and different views as to what is meant by "simulation coupling". For coupling beyond the boundaries of an individual software program, low-level mechanisms such as RPC, CORBA® or MPI [The93] can be found for distribution. These concepts enable coupling that delivers high performance and granularity with respect to data exchange between simulation components. However, at a low level of abstraction in terms of software technology, implementation of standardised communication protocols must be taken into account. So, every software program involved on the technical implementation level will require modification and maintenance. Hence, linking simulation tools at this level is heavily intrusive and should therefore be considered an inflexible form of coupling suitable only for connecting individual components that are readily compatible with each other. Accordingly, such simulation model "couplings" should rather be seen as distributing the modules of a single, overall software system for the purpose of performance enhancement. Using these tools, the actual simulation can be physically run on multiple computers. On the face of it, this kind of construction acts as a closed system. Such approaches are suitable primarily for environments where the entire code base of all components comes from a single source and can be developed and maintained as an overall system. However, with respect to extensibility and adaptability to changing conditions, such as the incorporation of simulation components not previously considered, this kind of approach is inadequate because it requires regular intervention by the software manufacturer. On the other hand, user intervention is not be possible. The steering and visualization framework CHEOPS [SYvWM04], which is based on CORBA, presents a similar approach to coupling simulations. The CHEOPS framework uses wrappers and adapters to combine existing simulation codes. A variety of applications have also been implemented using the FlowVR toolkit [AR06], but again here, coupling is only possible with modifications to the source code of each application. With such coupling approaches, compatible codes can be linked, even across various computers, to achieve a high performance level. However, integrating commercial tools into such approaches is difficult, in fact in practice it is usually impossible. SimVis [KFK07] is a simulation and visualisation tool developed by the company VEGA IT and used by the European Space Agency (ESA) to implement a "concurrent engineering" methodology. It comprises a component-based simulation system in which not only the simulation components themselves, but also related tools such as mission editors, report generators or spacecraft configuration tools as well as visualisation components are integrated. While the shortening of cycle times alone confirms the benefits of the integrated system, another important goal has been achieved: data consistency can be maintained across the numerous simulation steps as well as within the respective individual applications. The was achieved by introducing the XML-based Simulation Model Portability standard (SMP). This standard was specified by the SMP Configuration Board which consists of several European space agencies and industry partners involved in the development of SimVis. A hybrid type of coupling has been implemented and this allows some direct couplings, e.g. between simulation and visualisation components, but mainly it enables a consistent approach at data level through the use of a global data model. In addition to linking the software tools, there is also a need to connect the corresponding hardware resources. The field of grid computing is generally concerned with the issue of how distributed computing resources can be made uniformly accessible and, in the ideal scenario, used as a single virtual resource. There are some middleware architectures available in this field which, on the one hand, provide various tools and software libraries for resource management and, on the other, offer process monitoring as well as security and authentication modules. Popular grid middleware agents include Globus (http://www.globus.org), g-lite (http://glite.cern.ch), UNICORE (http://www.unicore.eu) and Condor (http://www.cs.wisc.edu/condor) [TTL05], although the latter should not be seen as grid middleware, but as a component that may be used to build grid middleware. Most of these middleware systems provide mechanisms for connecting other grids that work with other middleware systems. Hence a resource pool managed by Condor can, for instance, act as an individual resource within another grid. Another function of grid middleware is the dynamisation of resources. Hence it is common for data centres to provide resources that allow users to work interactively during the day, for example, then assign those resources to a grid overnight in order to increase its overall performance. Similarly, a company's workstation computers can be incorporated into a grid which releases those resources for other purposes, such as CPU-intensive simulations, based on either time or system utilisation. In order to reap the benefits of grid infrastructures, appropriate is software components are required. Grid middleware has proven to be the most flexible when dealing with Java applications. From a technical point of view, this seems logical because the Java code is executed by a virtual machine (VM) and can therefore be used regardless of any specific hardware architecture. If an application is not only to be executed "somewhere in the grid", but the application itself is to be optimised for the grid, e.g. by adding monitoring interfaces, etc., there are appropriate software libraries. With respect to the flexibility of grid middleware, however, things do not look quite so good outside the "Java world". Especially with regard to the afore-mentioned middleware systems, when this component was selected, native Windows applications could almost exclusively only be integrated with Condor. Here, the nature of grid architectures becomes apparent: the focus lies on the provision of computing resources and not on the provision of applications or services. Hence an end user cannot use the "grid" directly, but relies on the appropriate methods of access and applications available that can communicate with the grid and integrate its resources.

In recent years, the term cloud computing has become well established, even in the consumer sector. At first glance, this refers to harnessing grid architectures for end users, i.e. no grid resources per se are provided, rather services and applications are made available which run, transparently to the users, on distributed system architectures. However, the requirements of cloud computing sometimes vary greatly from those of grid computing: whereas grid computing is primarily about the distributed processing of CPU-intensive tasks (like a simulation chain), cloud computing focuses on users working interactively with various cloud services running transparently on distributed resources. In addition to linking the computing resources, it is essential that the simulations are also connected at data level if any benefits at all are to be reaped from such a link-up. Only when data that is actually relevant can be exchanged between the simulations has the link been successfully created. Linking at data level is described in the following section.

1.2 Application and Information Integration (Data Level)

In order to map simulation chains, the individual simulation tools must be technically coupled. Furthermore, the information required for the simulation tools to run, e.g. a finite element model, must be provided to enable interoperability of the simulation tools. In this respect, simulation tools use different methods for describing the model. Hence the information may be provided in various formats, for example, or the structure used for mapping the information within a format may vary. Likewise, the underlying semantics of the information, i.e. the meaning of the respective data, may also vary. In information technology, problems that may result from this heterogeneity are classed as integration problems and in this respect, one differentiates between application integration and information integration [LN07]. Application integration is concerned with the development and evaluation of methods and algorithms that allow application functionalities to be integrated along processes [CHKT06, GTT03]. Examples of this can be found in corporate environments, in particular, and relate to the integration of enterprise resource planning (ERP), for example, or customer relationship management (CRM) or production planning and control systems (PPS) along the business process chain [HGRZ06]. Information integration, on the other hand, is concerned with the evaluation of methods and algorithms that can be used to merge information from different sources [Vis04, He06]. Data warehouses are a popular example of the use of information integration methods. One could also cite metasearch engines, which gather and display information from numerous search engines, as examples of the use of information integration. What application and information integration do have in common is that both can only be successful if the heterogeneity between the pieces of information or applications can be overcome. A variety of preliminary studies have identified different heterogeneity conflicts [Gag07, GSSC95, SP91]. These can generally be classed as syntactic, structural or semantic heterogeneity conflicts. Syntactic heterogeneity relates to problems caused by the use of different data formats and models. Differences in the representation of floating point values are an example of this type of heterogeneity. Structural heterogeneity relates to differences in the use of the structure provided by a data format or model. Hence the XML data model, for instance, provides the ability to map information via attributes or in elements so that one and the same piece of information can be represented by different structures although the data model is the same. Semantic heterogeneity conflicts ultimately refer to differences in the meaning and representation of the data. A simple example of semantic heterogeneity is the use of synonyms to describe one and the same piece of information. So, information about the structure may be described by the term "microstructure", for example, in one simulation and by the term "structure" in another. In the past, a variety of methods and algorithms have been developed to overcome these heterogeneity conflicts. There have been attempts to overcome syntactic heterogeneity through the introduction of standards, for example. In the field of production technology, numerous exchange format standards have been introduced, including the Initial Graphics Exchange Specification (IGES), developed in the USA, the French standard for data exchange and transfer "Standard d'Exchange et de Transfer (SET)" and the German neutral file format for the exchange of surface geometry within the automobile industry "Verband Deutscher Automobilhersteller – Flächen-Schnittstellen (VDAFS)" [ES05]. Such standards are usually limited to specific disciplines and this inhibits all-embracing, cross-disciplinary integration. The Standard for the Exchange of Product Model Data (STEP), on the other hand, aims to define a standard not limited to specific disciplines [AT00]. This kind of standard is characterised by complex specifications. Implementation is therefore usually associated with enormous costs. Also, with this type of standard, modifications are slow to come into consideration and any necessary adjustments are not usually implemented promptly, if at all, because they are too specific for the respective discipline [CHKT06]. The is due to the use of particular standards already established within the discipline as well as the creation of in-house data formats that offer sufficient accuracy at a low level of complexity and are therefore not dependent on the use of standards. Approaches pursued to overcome structural and semantic heterogeneity include the application of the methods and algorithms of schema- and ontology-based integration [RB01, SE05]. This research looked in particular at data schemas based on the relational or XML data model [ES07]. The aim of schema- and ontology-based integration is to transfer source schema S into a target schema T, whereby data mapped in S should be merged in T. To do this, first a list of correspondences is created which connects the equivalent components of the schemas with one another and displays them. In the second step, based on these correspondences, transformation rules are applied in order to map the data from S in T. In so doing, correspondences are identified in light of the markings, the structure of the schema and the data mapped in S. In this respect, knowledge bases containing background knowledge about the application domain are often used with a view to improving the integration results [Gag07, GGS+06]. The background knowledge is represented using ontologies which have become established as an explicit, formal specification of a conceptualisation, i.e. concept formation [Gru93, SBF98]. There are a variety of research projects in this field which have produced different systems for schema – and ontology – based integration. COMA++ [EM07, ADMR05], developed at Leipzig University in Germany, contains a series of algorithms for identifying schema-based correspondences and for data transformation. COMA++ provides a repository for mapping internal data which is based on a homogeneous, proprietary format. Background knowledge can be provided in thesauruses and dictionaries in the form of ontologies. COMA++ uses this background knowledge to improve the identification of correspondences between schemas. In addition to COMA++, the FOAM Framework [Ehr07], developed at the University of Karlsruhe in Germany, also contains a variety of algorithms and strategies for schema- and ontology-based integration. Both systems feature analysis of the structure of the schema in light of the identifiers used. Semantic information not contained in the structure cannot be captured by these systems. Conversely, these systems are unable to identify different dataset semantics in a schema. Besides syntactic, structural and semantic heterogeneity, integration system architecture is also a key research topic. For application integration, service-based architectures with message-oriented communication have been found to be suitable. The enterprise service bus (ESB) has become well established as an architectural approach to application integration [Cha04, KWvL+07]. The ESB is a concept that allows heterogeneous applications to communicate in a distributed, service-based computer network. Information integration, on the other hand, is further subdivided into materialised and virtual integration. In materialised integration, the data is merged in a data storage device, or "data warehouse" [RALT06]. Here, the extract, transform and load (ETL) process is the general approach used [SVS05]. There are a number of systems that use the ETL process for materialised integration, including the Pentaho Data Integrator (PDI) [Lav06] and the Talend Open Studio [Jas07] developed by JasperSoft. In virtual integration, however, the data is not merged until a query is made. The data remains distributed across various data storage devices and is only merged for the purpose of the query. Integration systems based on virtual integration are referred to as federated information systems [Con97]. Once the simulations are linked at technical and data level, chained simulations can be run on the underlying grid architecture and simulation results produced. However, linked simulations are only of additional benefit if the simulation data generated can also be analysed, allowing new insights to be gained compared with separate analysis of the individual simulations.

1.3 Visualisation (Analysis Level)

There are numerous applications for visualising simulation data. Current simulation tools often comprise in-house solutions tailored to specific simulations. However, these are only suitable for visualising the datasets generated by this particular simulation software; generally, it is not possible to analyse data from multiple tools in a common context. Generic visualisation solutions such as ParaView [Par08], AVS (www.avs.com) or OpenDX (www.opendx.org), for example, are better suited to this purpose. However, these applications are designed to extract and display visual features, such as isosurfaces, from individual datasets. Furthermore, they lack the means of interaction required to deal with all the simulation results of a simulated process chain in a common context. With respect to embedding visualisations in distributed simulation environments, some studies have already been undertaken, but these were more concerned with the technical connection of visualisation tools in the broadest sense, similar to a video transmission [DFP+96, KPB+03]. Solutions are available for integrating distributed, real-time simulations and visualisations, as in FlowVR [AR06], and for coupling heterogeneous visualisation systems (AVS/Express and ViSTA) [DZF+07]. However, the known approaches involve intervention in the tools concerned, or only coupling very generic aspects, e.g. the observer and object positions within the visualisation, which can be exchanged between various programs with relative ease. However, even for this very simple type of coupling, appropriate interfaces to the applications are required. Such approaches can only be used to a very limited extent for a generic concept of simulation coupling and visualisation of data in one context. COVISE (www.hlrs.de/organization/av/vis/covise) is a modular, object-oriented software package for visualising scientific data. There are also modules from the field of computational steering (visualisation and interaction with simulations whilst they are running) as well as links to interactive post-processing. With COVISE, it is possible to set up simulation tools, steering components and post-processing/visualisation components as a distributed system. Again here, however, the focus is on providing software components in order to develop such distributed systems. It is not a solution that allows existing simulation tools to be integrated into such a system without modification.

2 Motivation and Research Question

Optimisation of production processes in terms of efficiency and quality is a general aim of the industry. Simulation software is already used in many research cases. This saves on both effort and costs compared with real experiments. However, the focus is on individual aspects of processes with associated simulation models which in most cases are barely linked or not linked at all. In practice, in such simulations, literature values or other approximated default settings are taken as the boundary parameters. This does not take into account any influences between the individual simulated aspects. Here, there is huge potential for optimising the simulation processes in terms of their accuracy. Besides modelling appropriate simulation processes by linking various simulation models, which would have to be done by experts in each of the simulated processes (see Chapt. 4.4 of "Integrated Production Technology for High-Wage Countries", Springer Verlag), there is also the question of how this link-up can be achieved technically. Both in research and in industrial practice, the human and technical resources involved are usually distributed across various institutes and departments and consequently across different buildings or even different locations entirely. Another issue concerns the data that has to be exchanged between the individual simulations: besides the technical implementation of data exchange, it is particularly important to ensure semantic consistency of the data. Furthermore, the methods and existing algorithms must be identified and refined in order to make the complex data structures in the field of material processing manageable and to facilitate the integration of other simulation tools used in production technology. The discussion and development of ontology-based integration methods in recent years provide a good starting point for development of the integration solution required. Construction of an appropriate ontology is a key challenge in this respect. This applies in particular to the study of ontology-based methods that allow data exchange despite dynamic simulation processes. New developments in artificial intelligence may make an important contribution here. Once the simulation tools and data have been successfully linked, both technically and semantically, then access to the network of simulation resources created has to be enabled. For this purpose, a suitable user interface must be devised with facilities for collaborative development of simulations. Ultimately, to gain new insights from the coupled overall simulation, analysis of all the simulation data thus generated must also be integrative. In particular, this calls for interactive access to the visualisations of all the datasets of a simulation within a common context.

3 Results

In this section, the results are presented according to the order in which the modules are found within the workflow of the proposed simulation platform: first, a simulation chain is defined and parameterised via a web interface with global access. This chain can then be run automatically (Sect. 3.1). Conversion of the data between the individual simulation tools and provision of the data for the subsequent visualisation is performed by the integration system developed (Sect. 3.2). Once all the simulation results are available, a manual processing step is executed in preparation for integrative visualisation (Sect. 1.3). Integrativity refers to both the visualisation itself and to the analysis of the simulation results as facilitated by the visualisation.

3.1 Grid and Web Interface

The usability of a distributed simulation environment depends largely on whether users can implement their simulation projects with it. In particular, users cannot be expected to produce configuration files for grid middleware which may also need to take account of modifications in the system infrastructure. The solution to this problem was to develop a web interface that allows the visual design of simulation graphs (see Fig. 1). Using this workflow manager, configuration data for the Condor grid middleware is generated automatically from the graphical representation. First, a "submission file" is created for each individual simulation. This file is used to

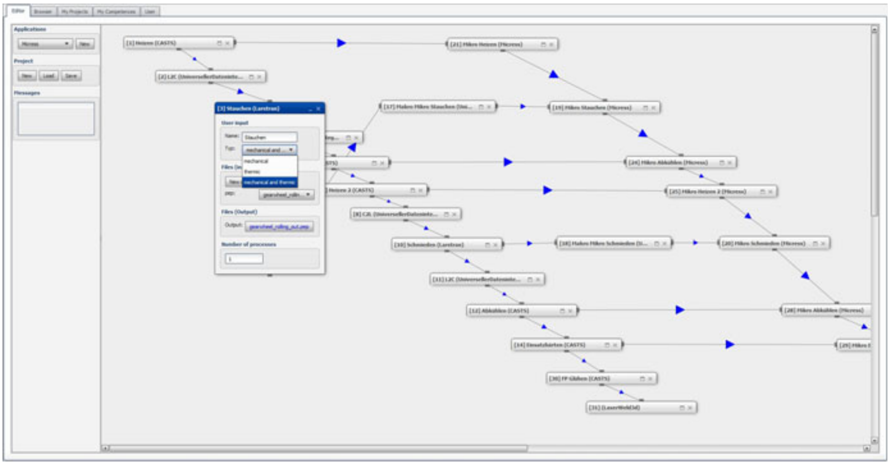


Fig. 1 Workflow manager for visual design of simulation graphs

define which resource the simulation will run on and which parameters should be applied. The variable parameters for each simulation (usually an initial geometry plus a proprietary control file) are entered in separate windows in the workflow manager. Certain additional options can be selected for each application and these are displayed separately on the screen (see Fig. 2). To reduce the complexity, only the parameters required for the test cases implemented are actually displayed on the screen.

The ability to integrate new simulation tools into the workflow manager easily and with low maintenance input is an important requirement on the system in terms of ensuring its practical usability. This is accomplished in that the web interface is managed on the platform server in an XML structure from which the graphical components are generated in the web interface dynamically during run time. In this structure, the types and names of the input fields are specified in a very simple form (see Fig. 2), which means no particular programming skills are required.

Once the individual simulations have been selected and linked, the resulting simulation graph can be saved. As an individual user is rarely able to configure every individual simulation in a chained simulation, a collaboration component has been integrated into the system: in their profile, users can add information about their competencies with respect to individual simulation tools. This information can be used to help select colleagues for particular simulations and give them access to those simulations (see Fig. 3). Once a simulation graph has been fully configured, it can also be launched from the web interface. Upon successful run, the results can then be downloaded (see Fig. 4).

At the technical level, the execution sequence is controlled and the specific resources selected using Condor tools. The execution sequence for the individual simulations is controlled by the Directed Acyclic Graph Manager (DAGMAN). The DAG files are generated directly from the sequence graphically modelled in the

Fig. 2 *left*: XML structure for describing a simulation, *right*: resulting element in the workflow manager

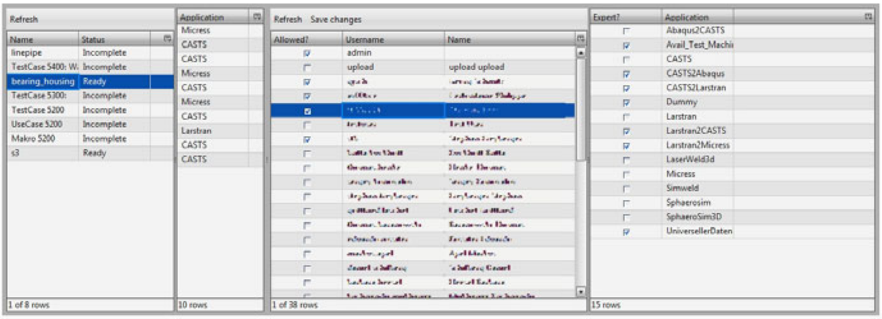


Fig. 3 Rights management. From *left* to *right*: projects, individual simulations used in the selected project, user list, competences of the user selected.

web interface (see Fig. 5 left). These files contain references to the submission files that are created for each individual program (see Fig. 5 right) – these control when an individual simulation is called up. It is possible to specify a particular resource in its entirety or just certain criteria, such as the operating system or the available disk space. If the latter is the case, then the system may use any resource on the simulation platform that matches these criteria. The submission file is also used to control which data a resource needs in order to launch the simulation and which data must be transmitted back once the simulation has finished. In fact, provided it does not breach licence conditions, a simulation program as such can also be dynamically transferred to any suitable resource for the duration of the simulation. Grid middleware is designed precisely for this type of dynamic resource management. It

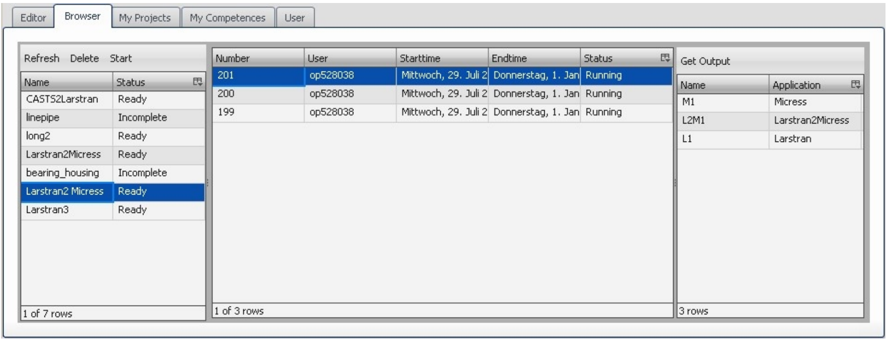


Fig. 4 Access to simulation chains already created, calculated instances thereof and the associated results

```
JOB 1_Magmasoft CASTING0 ./Larstran/1/Magmasoft CASTING0_submit
JOB 13_heattreatment0 ./Micress/13/heattreatment0_submit
JOB 19_Magma2vtk ./CASTS/19/Magma2vtk_submit
JOB 20_Magma2vtk ./CASTS/20/Magma2vtk_submit
JOB 9_CUTTING0 ./CASTS/9/CUTTING0_submit
JOB 15_APPLICATION0 Abaqus ./CASTS/15/APPLICATION0 Abaqus _submit
JOB 11_HEATTREATMENT0 ./CASTS/11/HEATTREATMENT0_submit
JOB 16_application0 ./Micress/16/application0_submit
JOB 14_MACHINING0 ./CASTS/14/MACHINING0_submit
JOB 8_casting0 ./Micress/8/casting0_submit
SCRIPT PRE 13_heattreatment0 /opt/condor_jobs_new/Micress/extract.sh
SCRIPT PRE 16_application0 /opt/condor_jobs_new/Micress/extract.sh
SCRIPT PRE 8_casting0 /opt/condor_jobs_new/Micress/extract.sh
PARENT 1_Magmasoft CASTING0 CHILD 19_Magma2vtk 20_Magma2vtk
PARENT 13_heattreatment0 CHILD 16_application0
PARENT 19_Magma2vtk CHILD 9_CUTTING0
PARENT 20_Magma2vtk CHILD 9_CUTTING0
PARENT 9_CUTTING0 CHILD 11_HEATTREATMENT0
PARENT 15_APPLICATION0 Abaqus CHILD 16_application0
PARENT 11_HEATTREATMENT0 CHILD 16_application0
PARENT 14_MACHINING0 CHILD 15_APPLICATION0 Abaqus
PARENT 8_casting0 CHILD 13_heattreatment0
```

```
Executable = /opt/condor_jobs_new/Larstran/Larstran.sh
Universe = vanilla
Log = Larstran.log
Output = Larstran.out
Error = Larstran.error
should_transfer_files = YES
when_to_transfer_output = ON_EXIT
InitialDir = bearing_housing/1290091363/Larstran/1
Requirements = (LARSTRAN_CAPABLE)&&(OpSys=="Linux")
Transfer_input_files = bearing_housing/1290091363/
Arguments = agthia
+wwwowner = tb552214
+jobname = 1
+app = Larstran
Queue
```

Fig. 5 Listings of a DAG description (*left*) and of a submission file (*right*)

helps achieve maximum flexibility and availability each simulation on the overall platform. In practice, however, most simulations are firmly bound to one hardware resource for technical licensing reasons.

Using the afore-mentioned tool from the field of grid computing allows a non-intrusive form of coupling. Hence, applications need not be modified in order to be used in the simulation platform presented in this paper. There are just a few prerequisites the software must fulfil in order to be linked. In essence, these can be summed up in two criteria: the software must be accessible using the command line and executable on an operating system for which Condor is available. In this respect, the approach described here is very different to most of the other approaches to simulation coupling in that they tend to require modification of all the software components involved. Since adequate implementation would be difficult, if not impossible, a solution is proposed that renders intervention in the individual simulation tools redundant. Nevertheless, the system architecture presented does allow such intervention in the simulation tools in order to, for example, decouple hardware and software resources. Like other grid middleware, Condor provides a programming interface that can be used to make in-house applications "grid aware", i.e. the fact that the application can be executed within a grid can be explicitly taken into account in the software. Hence, applications prepared like this can be dynamically (e.g. during a running simulation) transferred to other resources to ensure optimum utilisation of the resources available within the overall system. Another approach for decoupling hardware and software resources is the use of virtual machines. In this case, complete hard disk images from simulation computers can be transferred to, and launched on, any resource that can work with virtual machines. This improves controllability of the run time, even without intervention in the actual simulation software. However, it also results in a high proportion of data transmission, which is a huge disadvantage, especially in large networks. Such cases have not yet been realised with the implementation presented herein. However, at this juncture, it is worth pointing out that, if required, there are still lots of technical options for dealing with unforeseen problems in the future.

3.2 Integration System

The grid solution presented in the previous section enables interoperability of the applications on a technical level. The core objective of the integration system is to achieve interoperability of the simulation tools on a semantic level without negating the autonomy of the individual applications. In this respect, autonomy means the degree to which the various applications can be developed and operated independently of one another [Blu]. The development of standards and an application's need for implementation of such standards, in particular, constitute intervention in the autonomy of the individual applications. Often such intervention is not possible for technical, legal or competition-related reasons. Simulation tools developed within the field of production technology are characterised by different data formats, terminologies or definitions and the use of various models. The integration system developed creates a basis for overcoming the heterogeneity between the simulation tools, as described in Chapt. 3.2.2 of "Integrated Production Technology for High-Wage Countries" (Springer Verlag), thus enabling interoperability on a semantic level (see Fig. 6).

Integration, preparation and extraction are key functionalities in this respect. Through integration, data provided by a simulation tool in one data format is transferred to the central data store of the integration system then, using extraction, this data is converted into the data formats of other simulation tools while the semantics of the data are retained. To this end, there is a data preparation step prior to the actual extraction in which the data provided is transformed using semantic trans-

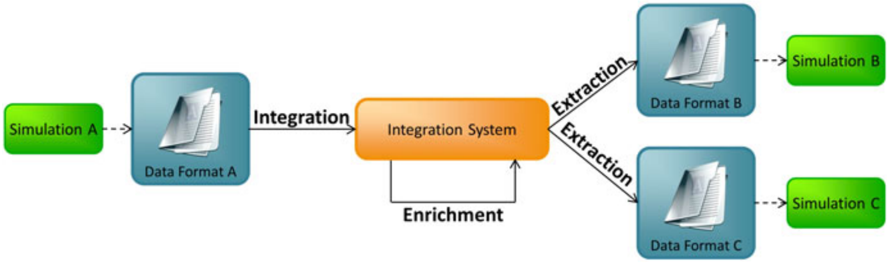


Fig. 6 Semantic interoperability between simulations

formations to make it suitable for extraction into a specific data format. Hence, some material processing simulation tools require, for instance, specification of the outer surfaces of a component's geometry. This information, however, cannot be contained in the data captured. Within data preparation, these surfaces are automatically identified and enhanced in the data. Extraction takes this data into account and can therefore deliver a valid geometry description. The integration system functionalities described above enable various, heterogeneous simulation tools to be coupled to simulation processes as required for implementation of the simulation platform in the sub-project "Virtual process chains in material processing" (see Chapt. 4.3 of "Integrated Production Technology for High-Wage Countries", Springer Verlag).

3.2.1 Architecture

The integration system architecture is based on the enterprise service bus architectural concept. This concept is service-oriented and therefore guarantees that distribution of functionality across numerous computers and flexible extension of the integration system is possible. Figure 7 illustrates the architecture of the integration system.

The integration server coordinates the integration, preparation and extraction processes and provides information about the status of individual conversions. Here, conversion means the sequential execution of integration, preparation and extraction. A conversion is therefore the transfer of data from one data format into another. Conversion requests are provided via the Condor middleware. Message-oriented communication between services and the integration server takes place via the integration bus. A database server is used for materialised integration of the data generated in the simulation process. The basis for the integration system is the AIIuS framework (Adaptive Information Integration using Services) developed in the Department for Information Management in Engineering at RWTH Aachen University, Germany. The AlluS provides a basic framework for integration systems in which applications with complex data models and formats are integrated along a process allocated during run time. It was built in this Cluster of Excellence in order to facilitate the development and networking of other integration systems in the field

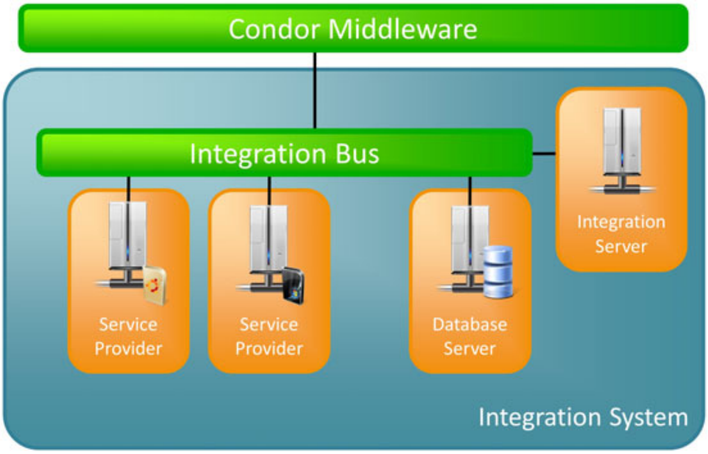


Fig. 7 Architecture of the integration system

of production technology. The framework is based on process-driven information and application integration. This means that each request is handled by means of a process of pre-defined work steps. In this respect, application integration involves tracking the provision of data for the simulation tool used in the next simulation process, while information integration entails integrating the data provided into the central data store of the information system. The following section presents these processes and work steps as applied for the integration system used for the sub-project "Virtual process chains in material processing". These processes and the associated work steps form an integral part of the AIIuS framework.

3.2.2 Processes for Integration and Extraction

As mentioned above, the Condor middleware communicates conversion requests to the integration system developed. A conversion request is characterised by the result data of a simulation tool and the location in the simulation process. The integration system must first integrate the result data into the collected simulation process data and then provide the data for the next simulation in the simulation process. In so doing, it is essential to overcome the heterogeneity of the data formats and models of the simulation tools by applying transformations. The simulation tools used in the sub-project "Virtual process chains in material processing" (see Chapt. 4.3 of "Integrated Production Technology for High-Wage Countries", Springer Verlag) provide their result data in file form. The AIIuS framework also supports the provision of data in databases or via application programming interfaces (APIs). Conversion requests are transmitted to the integration system via a Condor adapter implemented for the integration system, which forwards the Condor middleware request to the integration system in message form. Figure 8 below shows the basic data conversion process.

Fig. 8 Data conversion process

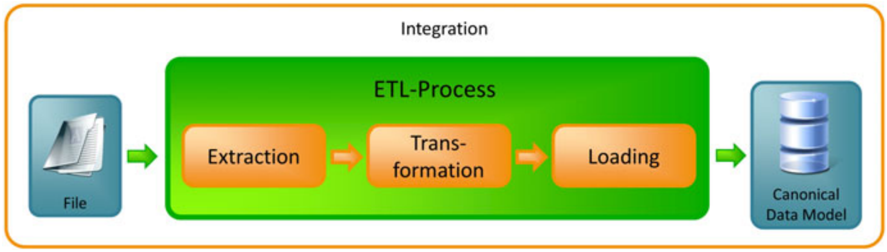


Fig. 9 Data conversion process

The integration stage of the process involves transferring the data from the data model of the data source into the central data model of the integration system, the "canonical data model" [HW04]. Given the volume of data and the complexity of the data structures, the canonical model used in the integration system is a relational database model. Besides the relational model, the AIIuS framework also supports other canonical data models. Hence the data can be deposited in the XML data model, for example. The integration process is based on the ETL process whereby first the data source is opened to allow the data to be extracted, then the data is transformed so that it can be loaded into the canonical data model. Data transformation to achieve the necessary syntactic and structural adaptation does not, in this case, produce any changes in the semantics of the data. Semantic transformation is not executed until the data preparation stage. In order to distinguish between the different types of transformation, the transformations designed to overcome syntactic and structural heterogeneity will hereinafter be referred to as data transformations, while the transformations executed in the data preparation stage to overcome semantic heterogeneity will be referred to as semantic transformations. Figure 9 below shows the integration process.

Once the data has been integrated into the canonical data model, it can be prepared for extraction. Within the AIIuS framework, this is achieved through a combination of methods from semantic information integration and artificial intelligence planning. Data preparation results in transformed data with semantics that meet the requirements of the data format to be extracted. In the sub-project "Virtual process chains in material processing", these requirements concern, for example, the element topology used in the component geometry, the indexing of nodes and elements or the units of state variables such as the temperature field or the strain tensor. Data preparation also comprises enhancement with new information, e.g. the temperature profile in selected points of the component or enhancement with information about the outer surfaces as described earlier. This preparation must be able to take place

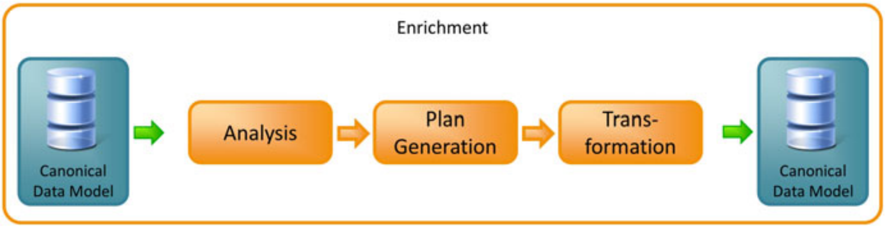


Fig. 10 Preparation process

even if information about the simulation process and the actual data basis cannot be made accessible to the integration system until during run time. Hence, processes and methods that enable data preparation under these circumstances too must be integrated into the integration system. Figure 10 shows the process underlying this preparation stage.

Data preparation uses the structure and methods of schema integration. In this respect, the focus is on overcoming semantic heterogeneity. Generic schema integration processes, such as DELTA (Data Element Tool-based Analysis) [CHR97], DIKE (Database Intensional Knowledge Extractor) [PTU03] or [MBR01]), which operate on the basis of the identifiers and the structure of the schema, may well provide an initial approach, but they are not sufficient for identifying the required semantic transformations of the data accumulated in the integration system. Likewise, instance-based processes like iMap [DLD+04], Automatch [BM02] and Clio [HHP+05], which are designed to identify correspondences using the datasets included, are also inadequate. This is because the actual transformation process depends not on the schema, but on a specific dataset and is only applicable for that dataset. For example, one and the same schema may contain a hexahedron-based and a tetrahedron-based element topology for defining the component geometry. If, however, a simulation tool only supports tetrahedrons as the element topology, then in the former case, data preparation must be performed and the hexahedrons must be converted into tetrahedrons. In the latter case, however, no preparation is required for the component geometry to be used in the simulation tool. The precise transformation process therefore depends on the state of the component geometry whereby this can be described through attributes such as element topology, material and other global and spatially distributed properties. In a first step, the preparation process analyses the data concerned according to the kind of attributes mentioned above and identifies the requirements placed on the attributes by the target schema. In a second step, a plan is generated which contains the transformation process for preparing the data. The actual semantic transformation of the data takes place in the third step. The methods and algorithms used for data enhancement will be described after this section. Below is a description of the extraction process which ensures that after it has been prepared, the data is transferred into the required data format and model. Similar to integration, the extraction process is also based on an ETL process which is illustrated below in Fig. 11.

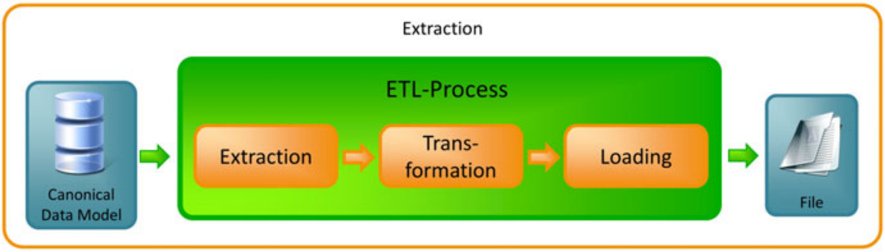


Fig. 11 Extraction process

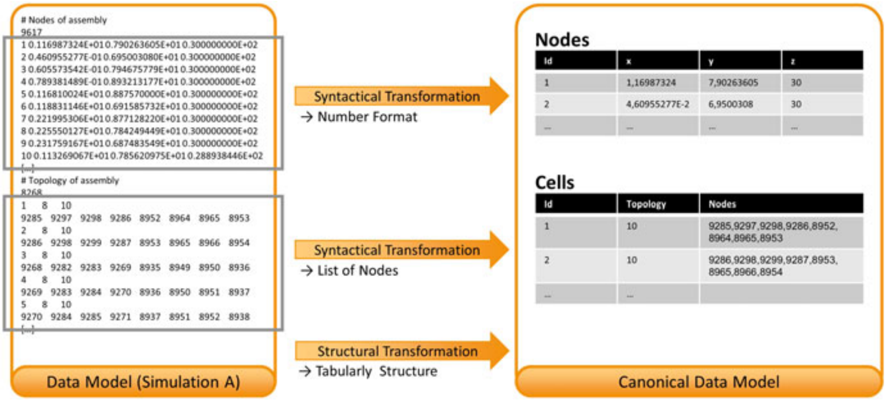


Fig. 12 Integration example

During extraction, first the data is extracted from the data store. Its structure and syntax is then adapted via data transformations to match the required data format and model. Finally, the data is loaded into the specific physical file. Implementation of the processes requires certain functionalities, which are provided by corresponding services. These services are described briefly below.

3.2.3 Services

The individual functionalities required in the processes are provided by services in a distributed system. Hence, a process is implemented by linking various services. In this respect, there are different types of services. Integration and extraction services are used to overcome the syntactic and structural heterogeneity, but do not alter the semantics of the data. For integration services, the functionality therefore lies in converting the data model of a simulation tool into the canonical data model of the integration system. By way of example, Fig. 12 shows the syntactic and structural transformation involved in the integration of a component geometry defined by nodes and elements.

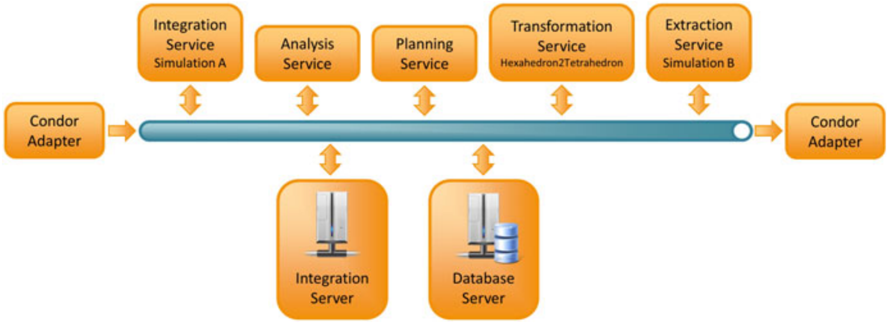


Fig. 13 Example of concatenation of services

Transformation services provide the data transformations required for data preparation, whereas the supporting functionality, required in particular at the point of data preparation, is made available by support services. While integration, extraction and transformation services are implemented in the actual integration system, support services are already implemented in the AIIuS framework. The message-based communication between the services and the integration server takes place via the integration bus. Due to the large data volumes, data is not attached directly to messages, but can be requested via attached connectors instead. By way of example, Fig. 13 shows how a conversion process works by linking services.

Service execution is monitored by the integration server, which can advise the status of individual conversion requests through this step. The services communicate with each other via the integration bus using a message protocol defined for the integration system. The specific integration and extraction service in each case depends on the data source and the data destination, while the specific transformation services are the result of the planning service. The services are provided by various service providers (see Fig. 7) whereby a single service may be offered by multiple service providers. This increases the number of conversion requests that can be executed in parallel.

3.2.4 Structures, Methods and Algorithms

Selected structures, methods and algorithms used in the AIIuS framework and the integration system based on that framework are described below. The methods and algorithms are based on the processes presented in this paper and implement the functionality required in the services. The integration and extraction services support the use of established tools for executing real-time ETL and ETL processes. The AIIuS framework already contains implementations for connection of the Pentaho Data Integrator (PDI), an open-source ETL tool in which most of the integrators and extractors for the afore-mentioned integration systems were developed. In-house implementations which require the use of third-party software, for example, are also

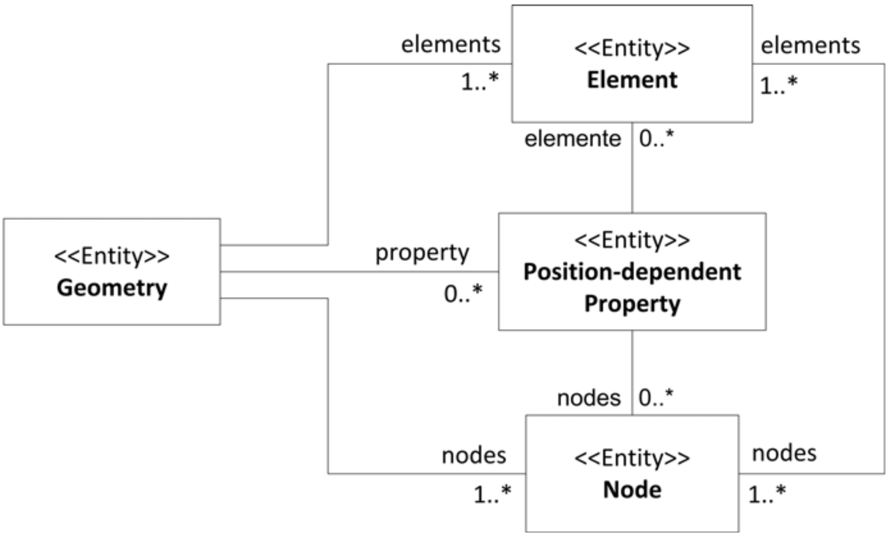


Fig. 14 Simplified data schema for FE model data

supported. As described earlier, the aim of the integration and extraction services is to transfer data to or extract data from the canonical data model. The canonical data model of this integration system is a relational data model. This model incorporates a data schema suitable for capturing the data generated during simulation of the material processing procedure. Figure 14 shows an extract from the data schema for capturing FE models.

This representation is not complete and is used here merely to facilitate the following explanations. On this basis, a geometry is composed of nodes, elements and position-dependent properties. Depending on its topology, an element is composed of any number of nodes, whereby one node can be associated with numerous elements. Furthermore, a position-dependent property is assigned to either nodes or elements. The data depicted in this data schema is analysed through analysis services. To this end, the algorithms developed use the information modelled in ontologies. In general, ontologies are used to model the specialist knowledge of an application domain. The ontology provided in the integration system contains information about concepts, relations and axioms from the domain of material processing procedure simulation. The ontology is modelled using the Web Ontology Language (OWL) [Stu09]. In this respect, analysis requires information about the existing data structures. The relationship shown in Fig. 14 between a geometry and its nodes is implemented in the domain ontology, which is illustrated in Fig. 15. The colour coding corresponds with the colour scheme used in the ontology editor Protégè [GMF+02].

In addition to the modelling of data structures of the application domain, data analysis also requires attributes to be defined. An attribute is a property fulfilled by one or more data structures. In domain ontology, an attribute is formally defined

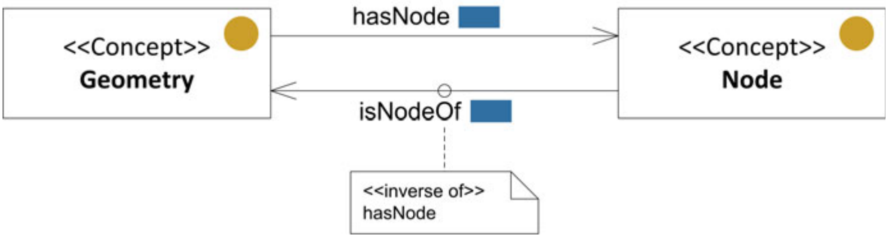


Fig. 15 Modelling the concepts geometry and nodes

by subsumption, i.e. the conditions that implicitly describe an attribute are defined. For example, the indexing of nodes or elements is an important attribute of the geometry models used in the simulations studied. Indexing in this respect can be closed or open. With closed indexing, there are no gaps in the numbering of nodes or elements, whereas such gaps can occur with open indexing. Likewise, the start index varies too. Hence the nature of the indexing in question as well as the respective start index used can be described as an attribute of a geometry. To determine such an attribute, the AIIuS framework allows rules to be defined within an ontology using the Semantic Web Rule Language (SWRL) [HPSB+04]. One rule used to check whether the indexing of a geometry is closed (or not) is as follows: *num* is the number of nodes within the geometry, max_{Id} is the highest and min_{Id} the lowest index used within the geometry. This rule states that a geometry has a closed node index if the number of nodes num is equal to the difference between the maximum index max_{Id} and the minimum index min_{Id} plus one.

$$max_{NodeId}(geo, max_{Id}) \wedge min_{NodeId}(geo, min_{Id}) \wedge num_{NodeId}(geo, num) \\ \wedge\, equal(num, max_{Id} - min_{Id} + 1) \Leftrightarrow ClosedNodeIndex(geo).$$

The minimum and maximum node index and the number of nodes are modelled separately within the domain ontology as properties of a geometry. Based on this rule, the required attribute is described via the definition contained in Fig. 16.

The ClosedIndexedNodes attribute is hereby defined as a subsumption of a geometry, which the SWRL ClosedNodeIndex rule fulfils. The explicit designation of the start index for the attribute adds this to the information provided by the attribute. Using this approach, it is possible to model attributes that provide answers to questions such as the following: “Which element topologies are used?”, “How are the nodes and elements indexed?” or “Are outer surfaces explicitly marked?” To evaluate the attributes, the analysis services implemented in the AIIuS framework use reasoners which allow conclusions to be reached based on the information modelled in the ontology. However, due to the huge volumes of data, the run time of reasoners such as [AAA+07] or FaCT++ [TH06] is unacceptable for the analysis services. Hence, similar to the KAON2 reasoner [MS06], the analysis services developed in the AIIuS framework support the definition of mappings between the data structures modelled in the ontology and the relational data model. Such a virtu-

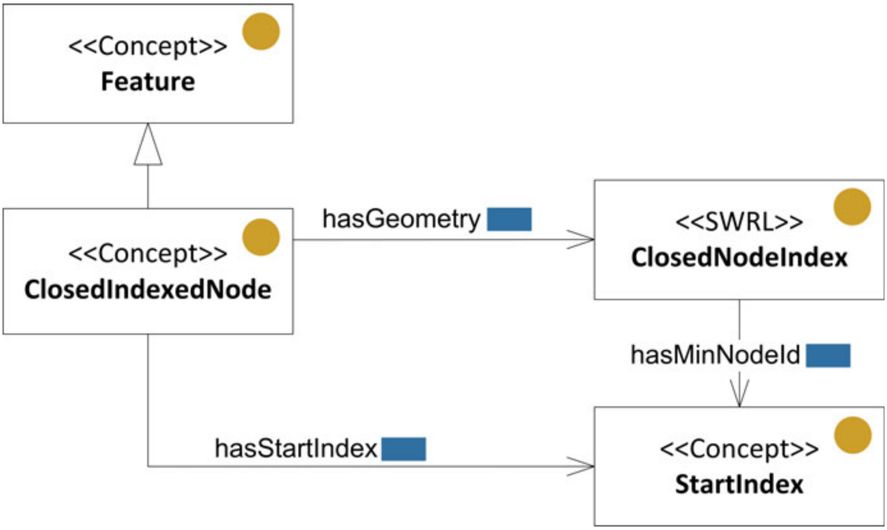


Fig. 16 ClosedIndexedNodes attribute

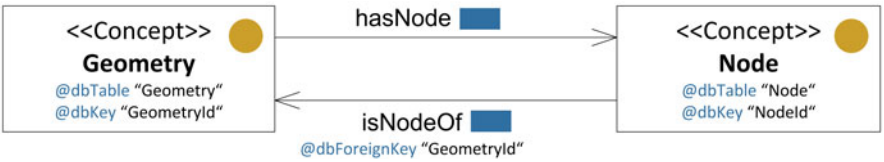


Fig. 17 Annotation-based mapping on a data schema

alised ontology allows the use of index structures and database query optimisation in order that conclusions can be reached quickly, especially where large volumes of data are concerned. Unlike the implementation in KAON2, however, the mapping between the relational data model and the ontology is not defined in a separate configuration file, but via an annotation in the ontology, similar to annotation-based programming. Hence, the relationship between geometry and nodes (see Fig. 15) is mapped by entering annotations, such as the following for example, on the data schema as illustrated in Fig. 17.

At present, the analysis services implemented in the AIIuS framework support five annotations which can be used to describe a mapping. In addition, other annotations are available to allow use of the aggregation functions of a relational database, such as those used in the above example. The algorithm for analysing a given database works as follows:

```
For each attribute m in the domain ontology o
    Generate request a using the annotations in m
        Submit request a to database and obtain result r
        Check r for fulfilment
        If r fulfils the attribute m
            Determine assignment b of m from r
            Add m with assignment b into the attribute list l
```

Listing 1 Algorithm for analysing attributes

The result of the algorithm is a list of n-tuples for each fulfilled attribute, whereby the data structure for which the attribute is valid is always in the first place. For example, the tuple

$$\text{NodeProperty}(\text{geo1}, \text{temperature}, {}^{\circ}\text{C}, \text{double}),$$

describes that the geometry geo1 has a spatially distributed property with the name temperature, which is specified in Celsius, and is presented as a double-precision floating point value. Assignment of the attribute is composed of the geometry, temperature, unit and data type. In addition, the analysis service determines a list of attributes to be fulfilled. To this end, the data format and data model requirements are also modelled in the domain ontology. Figure 18 shows how a requirement on the indexing of the nodes and elements of a data format is modelled in the domain ontology.

The data format given in this example is the VTK data format used for the visualisation [SML06]. This format requires that geometry indexing with nodes and elements begins with zero. To provide the functionality described above, the analysis services do not have to be adapted to a specific integration system; they are contained directly in the AIIuS framework. The analysis services are adapted to the respective application domain through provision of the domain ontology. For this to be possible, the domain ontology must import a framework ontology. The framework ontology defines the basic concepts required by an analysis service. The

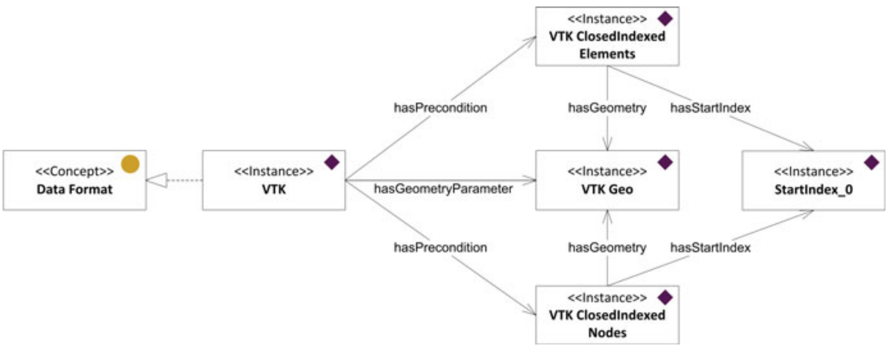


Fig. 18 Definition of a prerequisite in the VTK data format

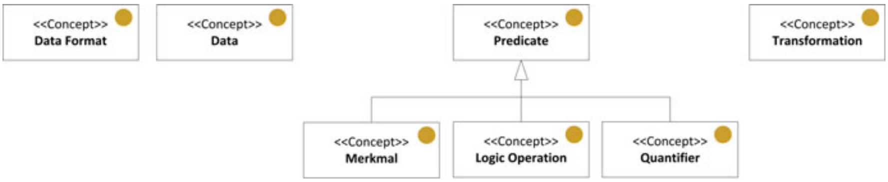


Fig. 19 Concepts of the framework ontology (extract)

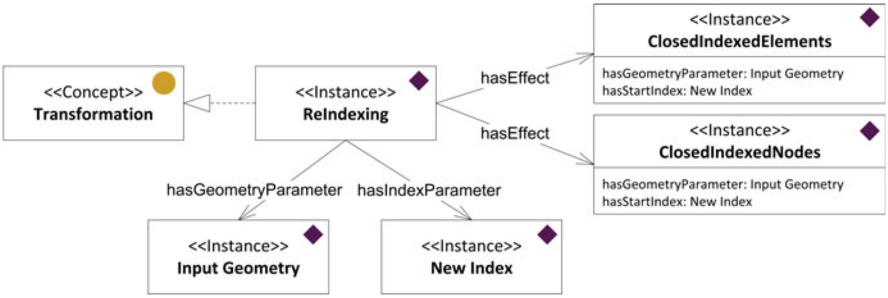


Fig. 20 Re-indexing transformation

analysis services are thereby able to infer the specific data structures and attributes from the domain ontology. The most important concepts of the framework ontology are listed in Fig. 19.

The concepts depicted in the framework ontology for modelling the data structure must be subsumable concepts of data. Attributes are modelled as subsumable concepts of attributes. Prerequisites of data formats can be described by using logical links such as And, Or and Not. The concept of transformation is not of any significance for the analysis services; it does gain relevance until in connection with the planning services. Planning services are used to determine a transformation process that allows semantic transformation of the data provided. The results of the analysis services, i.e. the actual state and the target state, are used for this purpose. One planning service produces a plan of transformation services that must be executed in order to generate the target state. The planning service also uses the domain ontology in this regard to specify a list of available transformations. Here, in addition to prerequisites, a transformation is also characterised by the effects that are generated through execution of the transformation. Figure 20 shows the modelling of a transformation for re-indexing a geometry.

In this diagram, for the sake of clarity, the relationships and their assignments are modelled in the instances as attributes. Re-indexing offers two parameters: the geometry, with changed state, and the start index to be used for re-indexing. The result of re-indexing is that indexing of the nodes and elements of the input geometry uses the new start index and is therefore closed. That way, any state changes to the data structures of the application domain can be described through transformations. Planning systems from the field of artificial intelligence are used to generate

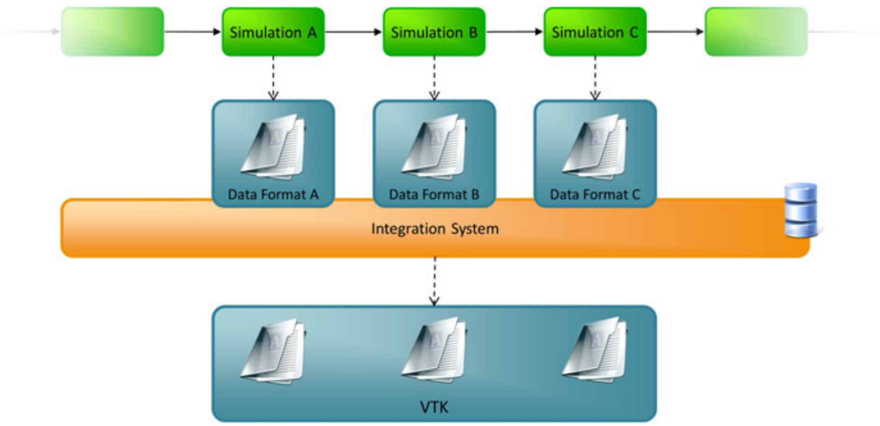


Fig. 21 Extraction of process data into a uniform data format

the transformations. The AIIuS framework can connect to any planning systems provided they support the Planning Domain Definition Language (PDDL). PDDL is a standardised language for defining classical planning problems. In this respect, the current state and the target state are described as well as actions that can change the state [FL11]. A translator has been implemented in the AIIuS framework to allow the planning problem in question to be expressed in PDDL. Using this translator, the data analysis results and the list of available transformations is transferred into the PDDL. Likewise, the translator also interprets the results of the planning algorithms used in the AIIuS framework and creates the transformation plan on this basis. Finally, this plan is executed using the transformation services. The integration system is therefore able to react to various situations and transfer the data into the required data format. In particular, this means all the data generated in the simulation can be provided for visualisation in the VTK data format (see Fig. 21).

As shown in Fig. 21, the integration system is designed in such a way that once process data has been integrated, the system can extract it into any desired data format. Hence, all the data delivered in a simulation process can be extracted into a uniform data format. The next section of this paper describes the integrative analysis that can be implemented thanks to this step.

3.3 Integrative Visualisation

For the simulation system described herein, visualisation must take into account various aspects which to date have not been addressed by conventional visualisation tools. Problems such as time synchronisation, for example, do not occur until the various visualisations have to be coordinated. Accordingly, such problems are sel-

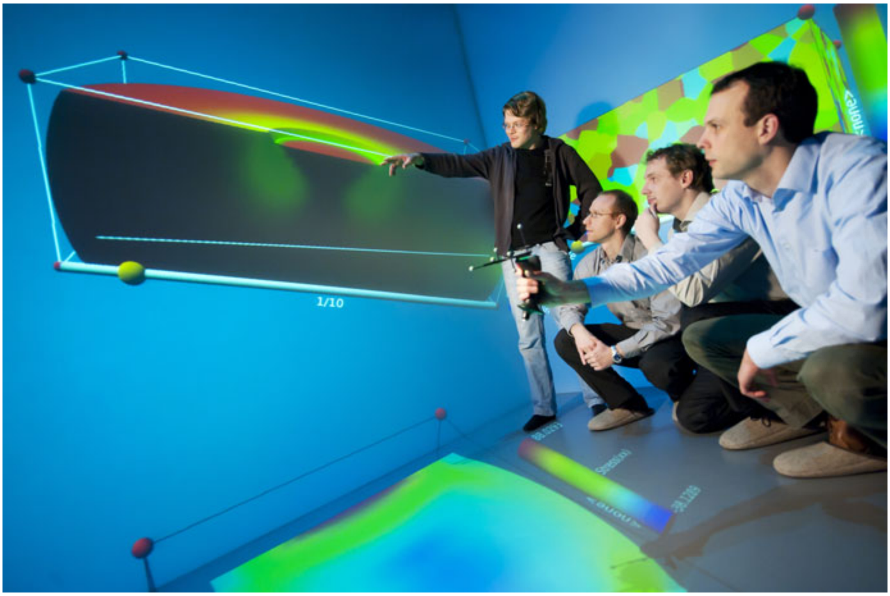


Fig. 22 Interactive analysis of simulation data in a fully immersive virtual reality system (CAVE)

dom resolved using current approaches. The approach presented herein addresses the following problem areas, which are discussed in detail below:

- Uniform pre-processing of datasets
- Decimation methods
- Interactive, simultaneous visualisation of multiple datasets
- Metamodel for dynamic management of visualisation data during run time
- Methods for interactive modification of the chronological arrangement of datasets
- Scalability of the visualisation with respect to the terminals that can be used.

Uniform pre-processing of datasets is facilitated by the transformation methods of data integration into the VTK data format as described in the previous section. In the context of the platform, the application concept is designed to allow individual visualisations to be prepared in a manual post-processing step using the open source tool ParaView and the geometric data thereby created to be visualised in a common visualisation solution. In this step, the volume meshes in the use cases can be reduced to one surface mesh that is more suitable for graphical representation. This enables standard visualisation methods of the software (in the simplest case, cut surfaces or isosurfaces (see Fig. 23) to be included in the data, thereby enabling potentially important information to be included in the common visualisation.

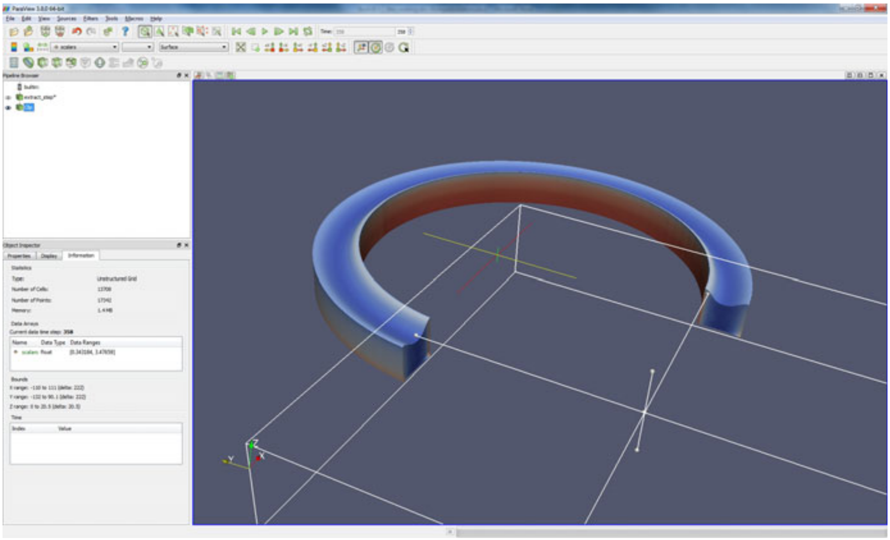


Fig. 23 Insertion of cut bodies into a dataset using ParaView

3.3.1 Decimation Methods

In some of the use cases studied (see 3D microstructure simulations, Chapt. 4.3 of "Integrated Production Technology for High-Wage Countries", Springer Verlag), the surface meshes created in the pre-processing step of the individual simulations are still so heavy that, using current hardware, they cannot be visualised with the refresh rates required for interactive visualisation (20 Hz). To achieve these refresh rates, the surface meshes of these datasets need to be decimated further still. Decimation algorithms themselves represent a major area of research. There are many different approaches to reducing triangle meshes or other types of mesh topologies and datasets [HD04]. The scenario in hand focuses on the reduction of triangle meshes. The quality of a decimation algorithm depends to a large extent on the type of datasets to be processed as well as the intended use of the decimation data. Thus, in order to evaluate a decimation algorithm, the application domains must be factored in. Accordingly, no algorithms can deliver optimal decimation results for all use cases. With commonly used algorithms, the default mesh is iteratively modified in order to obtain a representation of the dataset that is reduced, yet as accurate as possible in terms of the given metrics. This process continues until a stipulated criterion is met, e.g. the number of triangles remaining [SZL92]. Another approach is to create a new mesh that can be generated on the surface of the original mesh for example. In this case, the hard edges of the starting mesh are usually retained, while remeshing is performed in the regions of low curvature. With respect to the use case in question, algorithms from both categories were assessed for suitability for this particular application. A key aspect, particularly attributable to the algorithms from the first category mentioned above, is determining and parameterising the metrics for the cost function. In the simplest case, the geometric metrics of the surface mesh itself can be used and these can be inherently derived from the mesh. In this respect, it is mainly the local curvature of the surface that is used. This approach is problematic when using meshes containing nodal points connected to data values – which is precisely the type of mesh encountered in the field of simulations. Only in a few cases does the geometric surface curvature correlate with the attributes of the data values. To correctly determine the amount of distortion (or "costs") of a decimation step, therefore, all data values for the points concerned must be included in the cost function with an appropriate metric, whereby the decimation problem becomes a high-dimensional problem. Indeed there is research and algorithms in this area that try to take account of the data values through metrics. One well-known researcher in this field is Hoppe [Hop99]. Hoppe's algorithm, a widely used implementation, has been incorporated in the VTK library [SML06], but with limited success: for one thing, the algorithm appears to be unstable if, in addition to geometric attributes, data fields must also be taken into account in the cost function and, for another, the necessary weighting of the individual data fields represents a problem for the cost function in that initially the weighting can only be executed for scalar quantities. To take account of the higher-dimensional data such as vectors and tensors, typical in simulation information, scalar metrics would first need to be defined for this data. The difficulty here is twofold: the implementation of the decimation algorithm in question does not support this process, hence a further pre-processing step would be required to calculate the scalar metrics; and, even after such an extension, there would still be the problem that these metrics, in particular the weightings for the cost function, would very much depend on their individual semantics within the dataset. In the context of the simulation platform presented herein, the focus lies on developing the most generic methods possible for integrating various datasets into an overall visualisation. As of yet, it is not possible for special metrics and weightings that differ for each type of dataset to be taken into account in the overall architecture.

Instead of gradually coarsening a starting mesh, there is another category of algorithms that create a new mesh from the start in order to approximate the original mesh. One example of this is the Valette approach based on Voronoi cells [VC04]. In this approach, uniformly distributed surface meshes are generated. Above all, this means the dataset points that would be removed by decimation algorithms based on geometric error metrics can be retained (see Fig. 24). Hence, decimated surface meshes with a high information content can be created, even without consideration of special metrics. As part of remeshing, the data values need to be approximated to the new points of the surface mesh. To this end, the data of the points located in the vicinity of a point and its adjacent points in the new mesh is interpolated from the original mesh. Interpolation involves weighting the source data according to its distance from the new point (see Fig. 25).

To formally describe the quality of the decimated mesh, the individual semantics of each data field should be used with regard to a specific use case, which is difficult. However, from the results, as shown in Fig. 24, it is intuitively (and therefore without explicit formal description) obvious that the quality is higher – at least

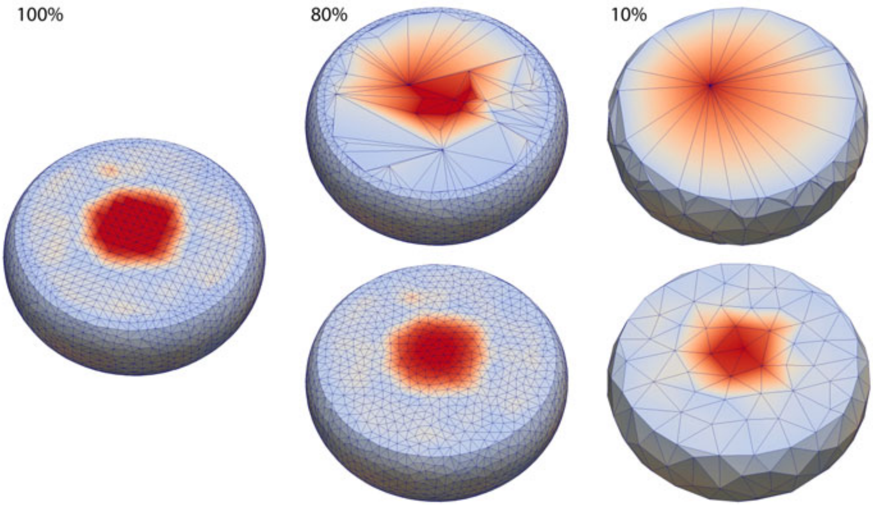


Fig. 24 Results of a traditional decimation operation [SZL92] (*top row*) and remeshing based on Voronoi cells according to Valette [VC04] (*bottom row*). Original mesh (*links*): 2500 points, decimated to 80 % (*centre*) and 10 % (*right*)

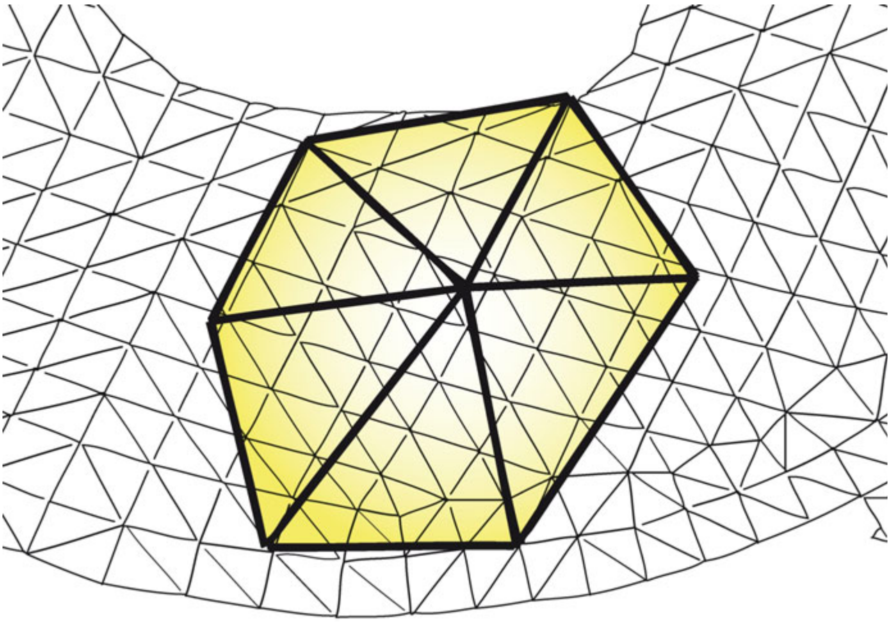


Fig. 25 Interpolation of the data values of all points of the source mesh located in the area of the adjoining triangles of the approximating mesh, weighted according to their distance

for datasets with important attributes in the data values in geometrically flat areas. Another special case regarding decimation occurs in the processing of surface meshes that have been extracted from a regular, three-dimensional grid, e.g. using the well-known Marching Cubes algorithm [LC87]. Due to the rectangular block structures this generates (see Fig. 26 above), an algorithm based purely on the geometric composition of the surface would reach its limits. Since all blocks have the same properties locally (i.e. a 90° curvature to the adjacent areas) and, due to their strong curvature, are recognised as important outer edges and are therefore not removed, a strong decimation can only be achieved if this special treatment of outer edges of the mesh is eliminated. This, however, can create holes in the mesh (see Fig. 26 below). Remeshing, on the other hand, can deliver significantly better results because it is not constrained to the vertices of the original block structure (see Fig. 26 centre).

The results attainable with remeshing and subsequent data interpolation, which differ significantly from the results of the standard VTK decimator, cannot be achieved without compromise. Run time and memory consumption, for example, are increased between two and five fold depending on the composition of the data. However, depending on the nature of the data, this is acceptable if no usable results with high decimation rates could be achieved with the other methods tested. The attempts to integrate data into the VTK implementation of Hoppe's decimation algorithm (vtkQuadricDecimation), for example, failed completely, which confirmed the experiences described in approximately 2002. In the approach presented herein, the solution used can decimate with either one of the two algorithms. The choice of algorithm can be made manually or integrated in the description files for the visualisation (see next section). Hence the entire decimation process for all visualisation results of a simulated process chain can be automated.

3.3.2 Interactive, Simultaneous Visualisation of Multiple Datasets

Special software has been developed to visualise the afore-mentioned geometry data extracted from numerous simulation steps in a common interactive context. This permits the implementation and investigation of methods for interactive manipulation of multiple simulation results in a common visualisation context, which is overlooked with traditional visualisation tools. In the project in question, the actual visualisation algorithms used to extract visual attributes from the raw data are not the main focus. This project focuses more on the manipulation of multiple datasets, both on a technical level in the application context and with respect to the interaction techniques that allow the user to navigate through the datasets and thus analyse them for the first time. Once of the technical challenges is visualising lots of large datasets in a common context. As demonstrated earlier, many datasets have to be reduced in order to guarantee smooth visualisation. For data analysis, however, it is preferred that full resolution can always be provided if need be. Hence, the study also investigated methods that allow dynamic switching between various resolution levels – or levels of detail (LOD) – of the datasets visualised. Furthermore, other methods

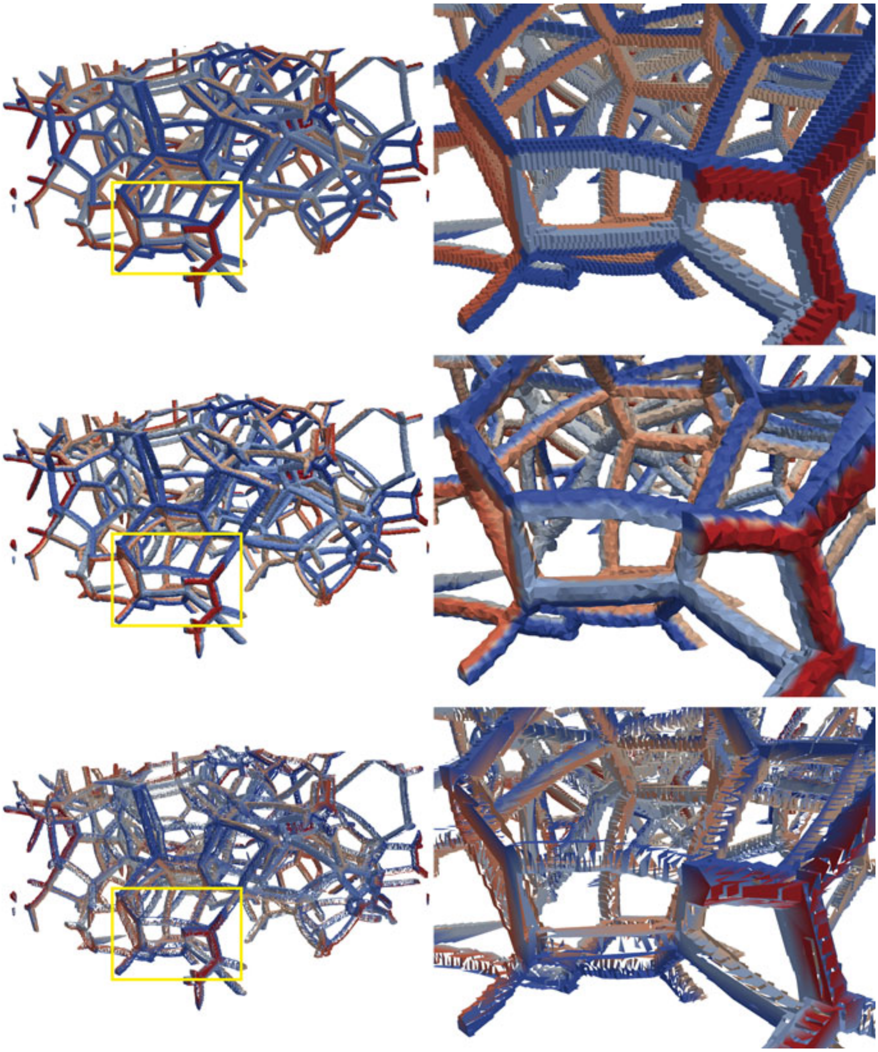


Fig. 26 Microstructure grid, 626,000 points (*above*), decimated to 125,000 points (20 %) according to Valette [VC04] (*centre*) and Schroeder [SZL92] (*below*)

that enable the LOD to be selected automatically according to various criteria were also investigated. Depending on the target system used, user interaction features can also be included, such as the user's line of sight in an immersive VR system. Traditionally, automated LOD selection methods for 3D geometries are used in the visualisation of expansive virtual worlds like those found in computer games [HD04]. The selection strategies used in this context are usually based on a distance metric according to which the LOD is selected. Objects that are far away, and therefore appear small, are visualised in a lower resolution, while objects that are close are displayed with a higher level of detail. These objects are usually relatively static with regard to the level of geometric complexity and the costs associated with visualisation. In this kind of system, when and where objects are going to appear is known in advance. Hence, various graphical effects and modelling tricks are used to optimise the geometric data in respect of visualisation. When considering such selection strategies in the context of visualising multiple dynamic simulation datasets, several problems emerge which the traditional selection strategies do not address: simulation data, for example, is time-variant so the complexity varies greatly with each time step. Furthermore, during interactive analysis, the chronology of datasets, and therefore the combination in which the various time steps of each dataset have to be represented simultaneously, is constantly changing. By comparison, in a classical virtual world, the objects move continuously, like in the real world, and their geometric complexity changes rapidly. Accordingly, the selection consistency for levels of detail between consecutive instants is always high. For scenarios where simulation data is visualised, such consistency and predictability only exists as long as the user does not have any interaction with regard to the chronological arrangement of the data. To date, there are no suitable selection strategies for scenarios such as these although in the future they will be researched using, amongst other things, the visualisation solution presented in this paper.

3.3.3 Metamodel for Dynamic Management of Visualisation Data During Run Time

When dealing with multiple datasets in one context, additional issues arise which require metainformation about the respective datasets. With parallel visualisation of multiple datasets, spatial and temporal position information must be available in order to provide a useful starting point for interactive analysis. Since this kind of data is usually negligible for an individual partial simulation, it is rarely present in the calculation results. The same applies for the units of measurement. Of particular significance here are the differences that occur when software tools from different manufacturers and/or problem domains are used which generally apply different systems of units, but from which data must be extracted and put into a common context. In the case in question, the integration component does ensure the semantic consensus of the datasets; in practice, however, time and again datasets crop up which do not originate directly from the simulation platform, but which are to be integrated into a visualisation. For a visualisation, in terms of the information required for correct arrangement of the datasets with respect to one another, whether it be of a temporal or spatial nature, the information for structuring the data as such is more important to start with. Simulation results are usually stored in the form of individual time steps. In this respect, it is essential to know the mapping of time on the time step discretisation in order to enable chronologically correct visualisation as well as the synchronisation of multiple datasets with one another. Also, the physical storage structure of individual time steps and the distribution of various data fields or sub-objects of a dataset on multiple files are not regulated in VTK. Hence,

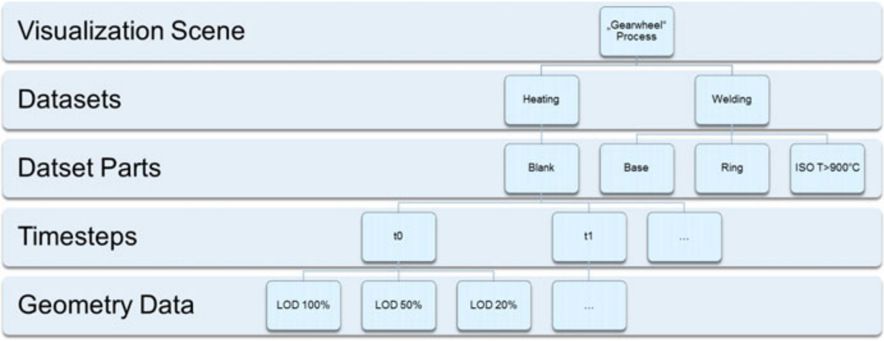


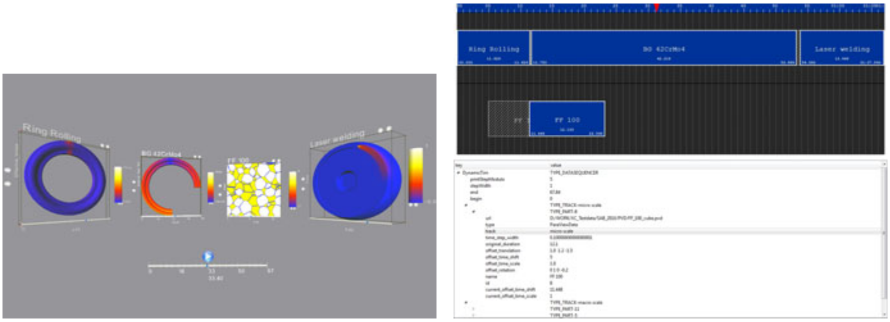
Fig. 27 Generic metastructure for describing discrete visualisation data

correct loading of a dataset also requires metainformation about the storage structure. While this requirement can be reasonably easily fulfilled when dealing with individual datasets because the datasets for a specific visualisation case are usually stored in the same structure, this step is a problem when dealing with various types of datasets. In an integrative visualisation solution, it must be possible for datasets to be loaded without a user having to manually assign individual times to a logical dataset.

Hence, in the case concerned, a metastructure was introduced which contains the persistent description of a visualisation scene in an XML file, but more importantly, has a run time data structure that allows different modules of the visualisation solution (e.g. LOD generation, LOD selection, various interaction modules or the visualisation component itself) to have uniform and abstract access to a common context of datasets (see Fig. 27). Here, the object-oriented programming paradigm as proposed by Fowler [Fow98] is used, amongst other things. This helps achieve a low degree of dependency between the various modules of the software. Nevertheless, all modules can operate on a common structure. Hence the metainformation model is highly flexible and offers dynamic extensibility both in the form of a run time data structure and a persistent scene/dataset description. On this basis, the metainformation model remains adaptable, even in view of rapidly changing requirements, without the basic structures of the software having to be modified.

3.3.4 Methods for Interactive Modification of the Chronological Arrangement of Datasets

In this project, using Wolter's time model [WAH+09], a generic methodology was created to allow discrete and even heterogeneously distributed time steps to be mapped on a continuous time basis. This makes it possible to control the individual datasets on a continuous time basis whereby an external view of the datasets is maintained, which is not dependent on considering the actual internal discretisation of time. To achieve chronological arrangement of all datasets, a continuous model for



(a) (b)

Fig. 28 *left*: Visualisation with embedded control elements for local timing (beneath the individual datasets) and global timing (bottom edge of image); *right*: Interactive 2D view of the chronology and metainformation of datasets

mapping and transforming time information is also included on this external level. In interactive analysis, this continuous model is dynamically modified using graphical control elements so that during data analysis, the user can interactively modify its chronology. Thus, any time steps and datasets can be displayed synchronously in time so that, for example, similar process steps of an overall process can be compared with one another. In addition to control elements being directly embedded in the visualisation context, there is also the facility to interactively display and modify the chronology of datasets together with metainformation on a separate surface (see Fig. 28).

3.3.5 Scalability of the Visualisation with Respect to the Terminals that Can Be Used

A visualisation solution for interactive analysis of the results of collaboratively developed simulation chains should be adaptable to various types of output devices and presentation situations. Individual project team members should be able to use integrative visualisation at their normal workstations or on small VR systems with stereoscopic display (see Fig. 29, left). Cooperative analysis or presentations in fully immersive high-end virtual reality systems (see Fig. 22 and 23, right) should also be possible. To this end, specific features in the overall architecture of the visualisation software must be taken into account since the bigger virtual reality systems run in a cluster on distributed systems. This significantly increases the complexity of the system compared with a conventional desktop application.

To achieve such flexibility with respect to input and output devices, the approach described herein uses the "Virtual Reality for Scientific and Technical Applications" (ViSTA) toolkit [Ass08], which, amongst other things, offers abstraction levels for this type of equipment. With the research presented, a platform was created that

Fig. 29 Fully immersive high-end virtually reality system (CAVE) (*left*) Mid-range virtual reality system with head tracking and stereoscopic representation (*right*)

enables individual simulation tools to be linked to a dynamic overall system. In addition to the purely technical link-up, the data levels were also encompassed to enable the semantic transformations of data required between the individual tools. To analyse the data generated, a visualisation solution was introduced which supports the analysts in gaining insights from the linked simulations. Based on the systems developed and the experience gained in this highly interdisciplinary environment, other new research topics will gain in importance in the future and these are described below.

3.4 Future Research Topics

In addition to coupling heterogeneous simulation tools, the integration system created within the framework of the Cluster of Excellent also enables the data generated in the simulation process to be integrated into a canonical data model. This allows systematic and system-supported evaluation and visualisation of the data, taking into account the underlying simulation process. Furthermore, systematic monitoring of the interim results can also be implemented. This next section will address the challenges and the issues requiring further research that have arisen from the creation of such an analysis component. First, the concept of "virtual production intelligence" will be derived. Then, the afore-mentioned methods of data analysis and data monitoring will be presented, together with the infrastructure this requires. The concept "virtual production intelligence" was selected based on the idea of "business intelligence" which became popular in the early to mid-1990s. "Business intelligence" refers to procedures and processes for systematic analysis (collection, evaluation and representation) of a company's data in electronic form. The goal is to use the insights gained to make better operative or strategic decisions with respect to business objectives. In this context, "intelligence" refers not to intelligence in the sense of a cognitive dimension, but describes the insights that are gained by collecting and processing information. With reference to the research topic of "virtual production intelligence" presented in this section, the data is analysed using analytic concepts and IT systems which evaluate the simulation process data collected with a view to gaining the desired knowledge. "Virtual production intelligence" aims to collect, analyse and visualise the data produced in a simulation process in order to generate insights that enable integrative assessment of the individual simulation results and of the aggregated simulation results. The analysis is based on expert knowledge as well as physical and mathematical models. Through integrative visualisation, the requirements for "virtual production intelligence" are satisfied entirely. Collection of the data, i.e. its integration into a uniform data model, has already been accomplished. Likewise, initial solutions for visualising the simulation results have already been implemented. Analysis and visualisation of the analysis results in an integrative environment are research projects that, upon successful completion in the future, would enable "virtual production intelligence". Integrating the results of a simulation process into a uniform data model is the first step towards gaining insights from these databases and being able to extract hidden, valid, useful and action-oriented information. This information encompasses, for example, the quality of the results of a simulation process and, in more specific use cases, also the reasons why inconsistencies emerge. To identify such aspects, at present the analysts use the analysis methods integrated in the simulation tools. Implementation of the integration system, however, opens up the possibility of unified consideration of all the data since it encompasses both the integrative visualisation of the entire simulation process in one visualisation component and the study and analysis of the data generated along the entire simulation process. Various exploration processes can be called upon for this purpose. What needs investigating in this respect is the extent to which the information extracted through exploration processes can be evaluated. Furthermore, how this data can be visualised and how information, such as data correlations, can be adequately depicted should also be investigated. To this end, there are various feedback-supported techniques that experts can use via visualisation feedback interfaces to evaluate and optimise the analysis results. The afore-mentioned data exploration and analysis may be further undertaken as follows: First, the data along the simulation process is integrated into a central data model and schema. Then, the data is analysed at analysis level by the user by means of visualisation. In so doing, the user is supported by interactive data exploration and analysis processes which can be directly controlled within the visualisation environment. Since it is possible to send feedback to the analysis component, the user has direct control over data exploration and can intervene in the analyses. From the present perspective, data analysis begets the following questions: Which exploration techniques are needed in the application field of virtual production for analysing the result data of numerical simulations? How can the results of data analysis be used in feedback systems to

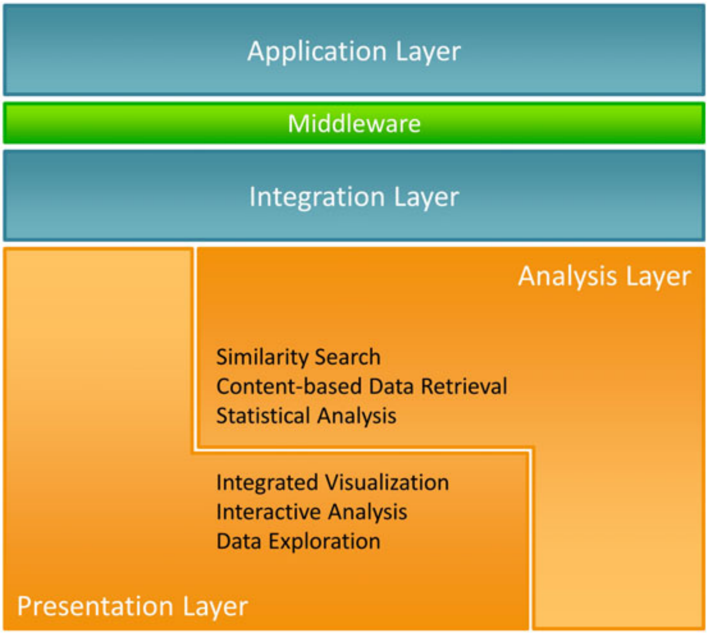


Fig. 30 Components of VPI

optimise the analysis results? How can the results of data analysis be represented in an integrated, interactive visualisation? In addition to retrospective analysis by experts, it is equally useful for the data to be monitored during the simulation process because such process monitoring enables, amongst other things, compliance with a valid parameter selection or other boundary conditions. If a simulation tool were to offer an invalid parameter value, this would lead to termination of the simulation process. Previous results could be analysed by experts using the methods available in data analysis in order to tailor the simulation parameters and thus guarantee that only valid parameters could be selected. Furthermore, the interim results could be evaluated using power functions which could be checked after the simulation has been run and the simulation results have been integrated. Similarly, process monitoring could also enable the extraction points-of-interest (POIs) based on functions which then would be highlighted in the visualisation. In data monitoring, process monitoring is integrated into the simulation process as a cross-sectional function. Within process monitoring, the following questions arise: How can power functions, POIs and monitoring criteria be formally specified within process monitoring? How can the information extract from process monitoring be used for process optimisation? Figure 30 shows the components of a system for implementing "virtual production intelligence".

The application level comprises the simulations that are called up along a defined simulation process. These are linked to one another via middleware which performs data exchange and is responsible for ensuring data integration and extraction within the simulation process. An integration server is provided for this purpose. Using a service-oriented approach, the integration server provides services for integration and extraction. The database server represents the central data model and serves as the central data store for all data generated in the process. The integration level was already implemented within the framework of the Cluster of Excellence and the application level was already connected to the integration level. Likewise, a visualisation component was developed which serves as the starting point for implementation of the presentation level. The presentation level is tasked with presenting the simulation results. As an example, dashboards could be provided for statistical control of production processes or for determining key performance indicators. Another possibility for data visualisation is a reporting tool which, amongst other things, would make it possible to evaluate erroneous processes so that the sources of error may be identified. It would even be possible to use tools from the field of artificial intelligence which could, for example, draw conclusions from temperature gradients and thereby draw attention to any anomalies in the results. This in turn could lead to the revision of simulation process modelling or of individual production processes. These examples provide an initial overview of potential deployment scenarios that could be supplemented with cooperative and interactive features. The user is given interactive control over the analysis. To accomplish this, the results achieved in the first phase of the project will be extended so that the user can modify the analysis parameters interactively from the visualisation and the amended analysis results will be fed back into the visualisation. The analysis level and the presentation level – the core of "virtual production intelligence" – are formed on the basis of these components. Implementation of these components would, for the first time ever, enable integrative analysis of heterogeneous simulation processes.

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The Virtual Production Simulation Platform: From Collaborative Distributed Simulation to Integrated Visual Analysis

Thomas Beer, Tobias Meisen, Rudolf Reinhard, Sergey Konovalov, Daniel Schilberg, Sabina Jeschke, Torsten Kuhlen, Christian Bischof

Abstract Computational simulations are used for the optimization of production processes in order to significantly reduce the need for costly experimental optimization approaches. Yet individual simulations can rarely describe more than a single production step. A set of simulations has to be coupled to each other to form a contiguous representation of a process chain. Eventually, simulated results have to be analyzed by domain experts to gather insight from the preformed computations. In this paper, we propose an IT infrastructure and software tools that aim at a rather non-intrusive way of coupling resources and domain expert's knowledge to enable the collaborative setup, execution and analysis of distributed simulation chains. We illustrate the approach in the domain of materials processing. Beyond means originating from the domain of GRID computing for resource management, a data integration component assures semantic data integrity between the simulation steps and stores simulation data in an application independent way. Thus, we can transform this data into native formats for each simulation tool, and finally into a format that allows for contiguous visualizations and an intuitive, comprehensive analysis of complete simulated process chains.

Key words: Virtual Production, Numerical Simulation, Data Integration, Visualization, Virtual Reality

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1 Introduction

Optimizations for an increasing efficiency in production are often best achieved by simulations. Because of high costs and time needs, it is hardly possible to realize this by means of experiments representing a complete production process chain. The usual approach to optimization with minimized experimental effort is the use of numerical simulations. But these mostly regard single aspects of the process and do not consider simulation results from other steps in the simulated process chain. Interactions of effects on different scales are oversimplified or conditionally included in existing simulation approaches. Consequently, key factors, e.g. the material's history through the process, are neglected. To overcome these weaknesses of typical simulation approaches, we propose the simulation platform AixViPMaP® (Aachen (Aix) Virtual Platform for Materials Processing) that allows for collaborative coupling of several simulation tools to enable integrative modeling of materials processing simulation chains. Such modeling is a complex task that requires the knowledge of multiple domain experts. While each expert is an expert in his domain and is proficient with at least one suitable simulation tool for that domain, the more critical parts of an integrated simulation are the interfaces between different simulation tools: It has to be assured that the simulation models fit semantically and data are consistently passed between the different simulation tools at the technical layer. In addition to the semantic model layer, physical simulation resources, i.e. computing hard- and software, need to be interconnected to form the physical simulation chain. One essential idea of the simulation platform presented in this article is the coupling of simulation domain expertise in form of both, the technical simulation resources as well as human expert's knowledge, following the basic principles of "Virtual Organizations" as known from the field of GRID computing [FK99]. Physical simulation resources are meant to reside at their natural location that is at, but not limited to, the domain expert's site. Our goal is the interconnection of those resources to form a virtual pool of simulations from which heterogeneous simulation chains can be built collaboratively and finally executed in an automated manner. A crucial step in the overall process is the final analysis of the generated data in order to gather dependable information from the simulation chain. Therefore, this step is included in our concept of a Simulation Platform. The paper is structured as follows: In the next section, we will introduce a specific example from the domain of materials processing, which we will use for illustration purposes for the remainder of this paper. Then we introduce a collaborative web based workflow manager that is used to specify and configure simulation chains (cf. Sect. 3.2). In Sect. 4 the Data Integrator will be presented. It assures semantic and syntactic data consistency within the simulation chain. Finally, some aspects of our integrated visual analysis and visualization solution will also be presented in Sect. 5.

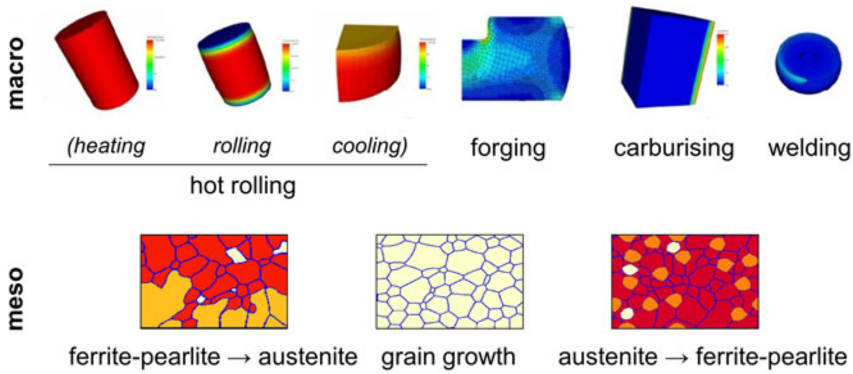

Fig. 1 Process chain for simplified gear component treatment on macro level and phase transformation on micro level

2 Use Case: Gear Wheel

One of the use cases that are realized within the AixViPMaP® is the production simulation of a gear wheel component (cf. Fig. 1). Several simulation tools, which model material's behavior on different levels, are interconnected to form a detailed representation of the process.

In this example, the simplified gear component treatment is modelled by six steps: heating, rolling, cooling, forging, carburising and welding. For the calculation of all relevant effects, two simulation tools are used on the macro level. The phase transformation with regard to the microalloying precipitation evolution is simulated on the micro level. By considering and combination of all simulated effects along the process chain, an integrated model of material state evolution throughout the process is created that is not possible by the separated use of several stand-alone simulations.

3 Distributed Collaborative Simulation Platform

3.1 System Architecture

The overall platform architecture is based on a GRID approach [FK99]. It utilizes the middleware Condor [TTL05] for centralized resource management and distribution of simulation tasks and data. Thus this middleware is used as a single point of contact for the platform users and hides the complexity of the distributed system. For details about the underlying GRID-based system, we would like to refer the interested reader to [CBKB08]. Beside the simulation resources, the Data Integrator serves as a special resource in its role as translator between simulation resources.

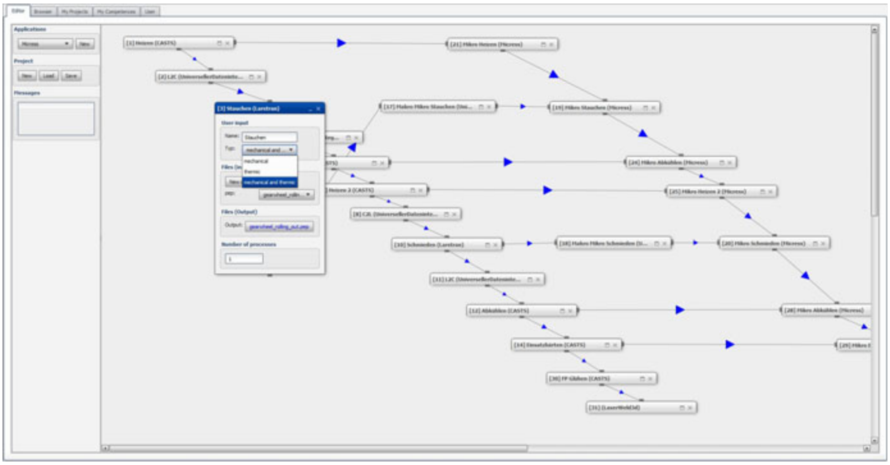

Fig. 2 Simulation workflow design in the editor view of the workflow manager

3.2 Interactive Workflow Manager

The workflow manager is a browser-based web 2.0 application that enables the user to visually design simulation workflows. These workflows are automatically translated into description files for the Condor middleware and can then be executed from within the web interface. Data translation and execution processes are scheduled by the centralized simulation platform server. The resulting jobs are performed on the different distributed simulation resources and the Data Integrator component. Because the entire process is managed by a server-side component, there is no need to install any software on client machines in order to design and execute simulation chains. Workflows are built by adding simulation steps represented by windows that hold configuration details for the appropriate simulation tool. These form the nodes of the underlying process graph. Dependencies between simulation steps are modeled by graph edges that define data input and output. For tools that require a translation step in-between, Data Integration (cf. Sect. 4) services are placed between two simulation resources (cf. Fig. 2). To provide the feature of collaboration, the application server supports a rights management system as well as project locking. With these tools at hand, a project coordinator can create new simulation projects, a domain expert can browse available and associated simulation tools to build up a team to further refine complex simulation chains. Finally, instances of created simulation workflows can be executed and monitored, whereas results from the finished instances can be accessed through the web interface by all team members of a simulation project.

Fig. 3 General process (application integration)

Fig. 4 Canonical Data Model

4 Data Integrator

4.1 Architecture

The integration of IT Systems is one of the most frequented topics in industry and computer science. Today, a multitude of integration architectures can be found which are used in different fields of application [HRO06]. Realizing the interconnection of applications is discussed in the research field of application integration. A general message-based approach [HW03] proposing a solution for the problem is depicted in Fig. 3.

Firstly, data generated by an application is bundled into a message that contains additional information about the sender and the destination. Secondly, the data is transmitted using established communication protocols. Thirdly, a translator is determined that converts the given message and the bundled data into the data format required at the destination. In the end, the data is transmitted to the destination. One central component is the translator. It resolves differences in message formats without changing the implementation of involved applications. However, if a large number of applications communicate with each other and by using this approach, a single translator must exist for each pair of communicating applications. This problem is solved by defining a so called Canonical Data Model. This model provides an additional level of indirection between applications' individual data formats (cf. Fig. 4). A translator that converts data into the Canonical Data Model is called Integrator. Conversely, a translator that translates data from the Canonical Data Model is called Extractor.

Systems that provide the described functionality are built upon a message oriented middleware (MOM). In the context of application integration, an architectural pattern that is based upon a MOM is the Enterprise Service Bus (ESB) [Cha04]. The schematic design of an ESB is depicted in Fig. 5.

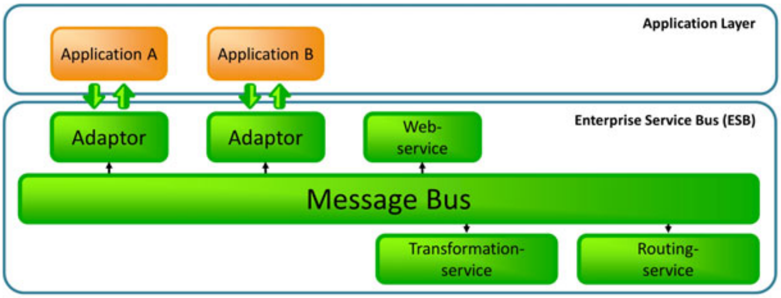

Fig. 5 Schematic Design of an Enterprise Service Bus

The communication between applications and services is realized by using a message bus. It is a combination of a Canonical Data Model and a messaging infrastructure to allow different systems to communicate via shared interfaces. Normally, an application cannot provide data in the message data format, hence adaptors are used. An adaptor consists of a translator component that uses transformation services to translate data of a concrete application into the conceptual data model of the ESB. Besides, it has a routing component that uses routing services to transfer data between the message bus and the application. The design of an ESB only solves the problem of data propagation, thus the interconnection of the different heterogeneous simulations. A postponed analysis of data is hardly realizable because of missing data storage or a common interface to query data. One widely accepted solution, to solve this problem, is to consolidate the data into one data storage, using a process, whose denomination is established as Extract-Transform-Load (ETL) [Whi05]. The architecture of the developed Data Integrator combines both approaches. It is based upon the ESB architectural pattern extended by a shared database used to consolidate data of a simulation process. The schema of the shared database represents the Canonical Data Modell of the ESB. The execution of applications (via batch processing or remote procedure calls) and the routing of data are implemented using the middleware Condor. The basic architecture of the Data Integrator is depicted in Fig. 6.

Service Providers are a collection of integration, extraction and transformation services. The different services are triggered by the Integration Server according to the given data format and the context of the data. The context is defined by the simulation process and the concrete process step and enables the process related storing of data. The Integration Server determines the data translation, more precisely the process of required transformation services, during run time based upon the data gathered during the simulation process. Hence no specific adaptors are needed. Therefore, methods of artificial intelligence and the semantic web are used. The following section describes these methods more concisely.

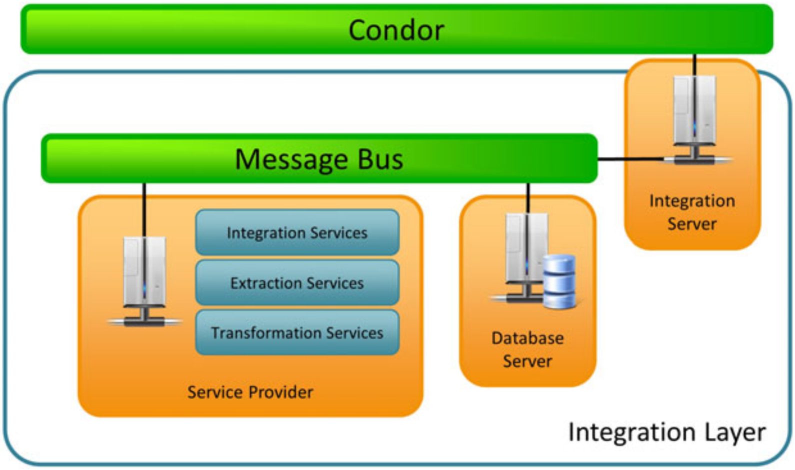

Fig. 6 Basic Architecture of the Data Integrator

4.2 Adaptive Data Translator

Independent of the type of the integration problem, the determination of a data conversion that translates data of a given representation into another one is necessary. Thereby, different kinds of data heterogeneity are distinguished (syntactic, data model, structural and semantic heterogeneity) [Les07]. Negotiating the heterogeneity between two different data representations is the goal of a data translation. One solution that is often used in enterprise application integration scenarios is the implementation of specific data translators. More dynamic scenarios like peer-to-peer systems or agent based systems require data translators that have to be determined during run time. As the concrete simulation process is defined during run time, a combination of both scenarios is necessary. The need for a dynamic solution is reinforced by the complex data formats used in the context of the involved simulations, which results in a complex semantic of data. The general concept of data translation is sketched in Fig. 7.

In general, data translation consists of translating data $\mathbf{d}$ of a concrete data model into data $\mathbf{d}'$ of another data model using additional meta-information $\mathbf{m}_d$ and $\mathbf{m}_{d'}$ about each data model. This can be expressed by the following operator:

$$Translate(d, m_d, m_{d'} = d'). \tag{1}$$

The preferred data models in the field of material processing simulations are structured text files using different key words and structures to represent the data. In general, no query languages or interfaces exist to read the data in a structured and standardized way. The presented data translation considers this characteristic of material processing simulations. It is based upon a three-step algorithm. In the first step, the syntactic and data model heterogeneity, more precisely the representation

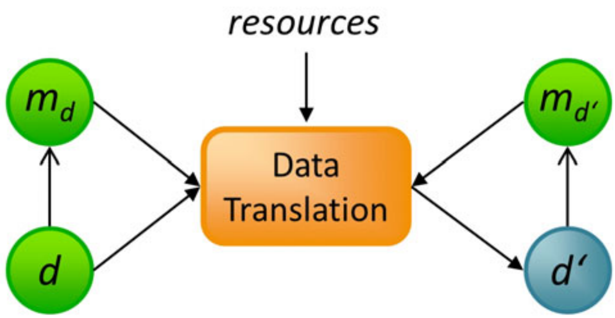

Fig. 7 General Data Translation Process

of the data, normally a text file, is handled by specific integrators. Consequently, the data is stored in a shared database using a Conceptual Data Model without changing the structure or semantic of the data. The second step negotiates the structural and the semantic heterogeneity by using an adaptive data translation component. In the third step the transformed data is written into the data format of the target application using an extractor. The components of the algorithm and the described process are depicted in Fig. 8.

Integrator and Extractor are implemented using existing data integration solutions like the Pentaho Data Integrator [Lav06] or, if they exist, native libraries developed by the manufacturer of the simulation. The problem of the negotiation of the structural and semantic heterogeneity is solved by the Adaptive Data Translation. It can be categorized as a matching problem [ZKEH06]. Matching, in general, is defined as the process of finding relationships or correspondences between entities of different data models [ES07]. In particular, the examined matching problem is the finding of relationships or correspondences between a concrete dataset and the structural and semantic requirements of the target format. The solution of a matching problem is a set of relationships or correspondences, the so called alignment. While using an alignment, a mapping between the data models can be extracted that enables the translation of the concrete dataset. The developed solution for the given

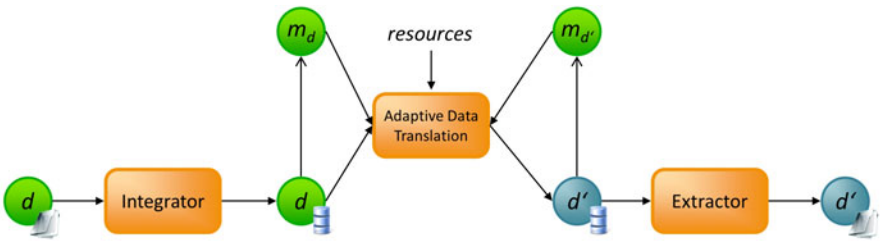

Fig. 8 Data Translation Process

matching problem focuses on the structural and semantic matching, so that the concrete dataset can be transformed to map the requirements of the target data format. Finding the alignment requires domain specific knowledge and information about the existing data transformations. The knowledge is represented by ontologies. An ontology is a formal, explicit specification of a shared conceptualization [SS09]. The concrete ontologies contain information about the data schema of the Conceptual Data Model as well as data transformations specified for the considered domain. Additionally the ontologies contains domain-specific data features. Data features are properties of data that can be fulfilled by a concrete dataset. Examples of data features are the existence of a space-resolved attribute likes temperature or the dimensionality of the considered geometry, describing the assembly. The algorithm to find the mapping is sketched in Listing 1. The input of the algorithm consists of the concrete dataset **d**, the ontology $\mathbf{O_{domain}}$ and the identifier of the target data format **t**.

```
01:  for each domain specific data feature f in Odomain
02:    analyze if f is fulfilled by d
03:    if f is fulfilled
04:      add f to feature list ld
05:  determine target feature list lt and transformation list a
       from Odomain
06:  find plan p by solving the planning problem defined by
       initial state: ld
       goal state: lt
       transformation list (actions): a
07:  translate p into mapping m
```

Listing 1 Mapping algorithm

Using planning algorithms like FF_{Plan} [HN01], the mapping is determined by the list of features $\mathbf{l}_d$ that are fulfilled by **d** and the list of features $\mathbf{l}_t$ that have to be fulfilled, so that the data can be extracted into the target data format **t**. This adaptive data translation and the concrete implementations of Integrators and Extractors solve the mapping problem and enable the interconnection between heterogeneous simulations of material processing.

5 Virtual Integrated Simulation Analysis

The ultimate goal of performing simulations in general and coupled simulations in particular is a deeper understanding of the underlying processes and effects. Therefore, efficient means of data analysis are a mandatory component in the overall workflow. Thus, as the simulated phenomena can rarely be detected by generic computational methods, paradigms and tools from the domain of scientific visualization serve to transform the vast amount of numerical results into a readily accessible visual representation. After all simulations have successfully delivered their results and thus formed a contiguous representation of material, visualizations of the different production steps have to be merged into a common context. This context involves not only multiple scales, but also different temporal and spatial resolutions as well as different data fields (e.g. temperatures at macro level, grain identifiers at micro level). In the following sections, we present concepts that address multiple issues, which emerge when scaling metaphors and techniques originating from classical single-dataset-visualization to a multipledatasets environment, which forms the representation of a complete process chain rather than a single aspect of it.

5.1 Unified Post-Processing

With the Data Integrator (cf. Sect. 4), we have the opportunity to get all simulation data translated into a format suitable for visualization. Therefore, we chose the PolyData-Format of the widely used Visualization Toolkit software library (VTK) [vis06]. This enables us to use free post-processing tools like ParaView [par08]. Again, after the configuration of the initial simulation chain, the domain experts' knowledge comes into play when preparing data for the integrated visual analysis. Within the post-processing tool, standard visualization objects like object surfaces, cutplanes or isosurfaces – more sophisticated visualization primitives are available as well – can be extracted for each dataset interactively. We propose a manual preparation step at this point, as the configuration of a visualization pipeline that filters semantically important information out of the heterogeneous simulation results from different domains is not yet fully automatable. For performance reasons, we just export the surface meshes of the datasets and do not drive the complete visualization pipeline in real-time during the analysis process. Besides performance issues, it is also a memory problem to keep full unstructured volumetric data for all simulations in-core at once. We are targeting a wide range of display systems (cf. Sect. 5.4) and thus are faced with different amounts of data that can be handled interactively. Thus, we need to incorporate decimation algorithms and runtime strategies to enable an interactive visual analysis process. In the following, we present a rather pragmatic approach to decimation of heterogeneous visualization data.

5.2 Preparing Decimated Visualization Data

Decimation algorithms do have a long history and although many different approaches are known [HD04], there is no one-fits-all algorithm that guarantees optimal results for arbitrary input data. While error metrics based on geometry are widely used across the variety of decimation algorithms for triangle meshes, simulation data – due to its various domain specific data fields – inherently leads to individ-

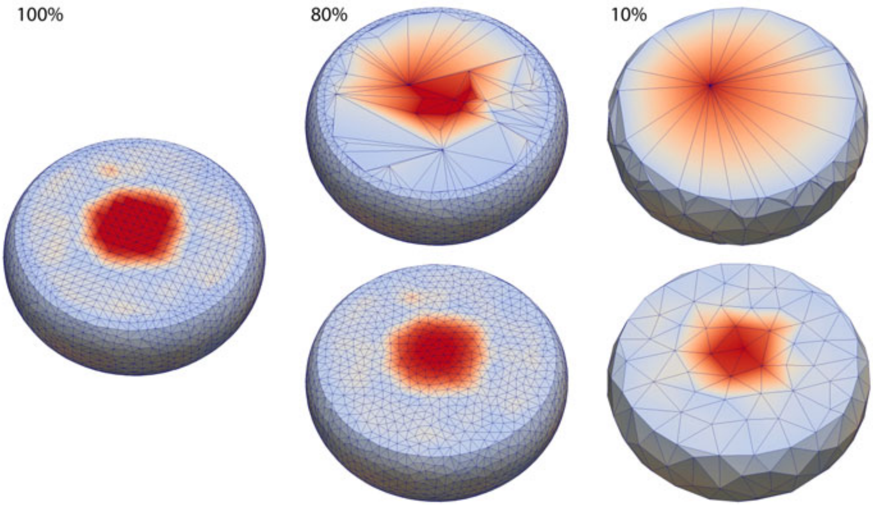

Fig. 9 Results of a traditional decimation algorithm [SZL92] (*upper row*) with the ACVD Algorithm [VC04] (*lower row*). Original mesh (*left*) 2500 points, decimated to 80 % (*mid*) and 10 % (*right*)

ual error metrics defined by domain specific semantics. These are specific for each of the process steps in a rather soft way that cannot be used directly to parameterize decimation algorithms. There are algorithms that, beyond geometrical metrics, take into account data values [Hop99], but selecting and weighting fields for this kind of metric again involves domain specific semantics, not to mention that computational complexity increases with the number of fields that are taken into account for an error metric. Hence, it renders those metrics unusable because of the large amount of fields in our datasets. But as the decimated visualizations are only meant to provide an overview even for large process chains that do not allow visualizing all datasets at full resolution at once, we propose the use of a pragmatic decimation method based on approximated centroidal voronoi diagrams (ACVD) [VC04] that results in reasonably uniform mesh resolutions. This way, data values on flat surfaces that would be rejected by traditional geometric error metrics are preserved, while not generating too much computational load. For most datasets in our chains, this approach delivers good quality (cf. Fig. 9).

For the few other datasets, we explicitly configure our automated decimation tool to use a traditional decimation algorithm [SZL92] as provided by VTK. This configuration is made by the user and can either be set globally for a decimation session or on a per-dataset basis by adding a special tag to the meta data structure we use for the visualization data. Further development of the overall simulation platform may thus inject this tag automatically, e.g. based on the simulation tool that originally produced the results that are being decimated.

5.3 Integrated Visualization

After all visualization data and the corresponding decimated version of it have been made available to the visualization front end, the integration into a common visualization context in a concerted manner enables the analysis and the discussion of phenomena along the whole process between domain experts. The requirements for such an integrated Visualization System are special compared to traditional visualization solutions for single datasets: Multiple datasets are representing material and work piece states at different spatial scales, e.g. grain level (magnitude of μm) and work piece scale (magnitude of m), spatial locations, temporal scales (ranging from seconds to hours for sub-processes) and temporal locations. These aspects provide the parameters that specify how the single simulations are to be orchestrated to form a contiguous representation of the simulated process chain. The application could now use these parameters to build up a matching visualization scene. But with this kind of 1 : 1 setup, the analyst would at most get a rough overview of the process: Regarding the different spatiotemporal scales of the different simulation steps, the expert would not be able to see a micro structural dataset at all during the analysis process (the whole dataset represents a region of approx. $200\,\mu m^3$). Furthermore, if the application would enable the user to zoom into the micro structural dataset far enough to actually see it, she will lose track of the work piece context (about $10\,cm^3$) that micro structural data belongs to. From the temporal view, e.g. the quenching or the laser welding process is too fast to see anything if analyzed in real time, while a carburizing process takes several hours to complete (cf. Fig. 1). For an interactive visual analysis, this real-world configuration is unreasonable. Thus we propose methods to control the spatial and temporal relations in an interactive way. We enable the analyzing domain expert to set up the whole virtual process visualization to suit his needs and to deliver an integrated visualization setup that helps analyzing or presenting special phenomena that cannot be explained by analyzing just a single dataset of the simulation chain. Each single dataset can be sized and placed in a spatial and a temporal manner. Thus it is possible to compare all datasets in interactively changeable configurations, but still in a common context. In order to avoid a lost-in-data situation and to help the analyst keep track of the spatiotemporal relations the datasets form in the simulated process chain, we propose a hybrid 2D/3D user interface we call the dataset sequencer. It focuses on interaction with the temporal setup of a visualization environment during the analysis process. Editing of temporal locations and durations of the single simulation visualizations in a common temporal context can be performed by means of intuitive dragging actions. With this component of the visualization system, we offer a 2D "desktop" and 3D "immersive" means of interaction, which both can be used on a wide range of target systems (cf. Sect. 5.4). While a detailed discussion would be out of the scope for this article, Fig. 10 gives an impression of how our approach looks like.

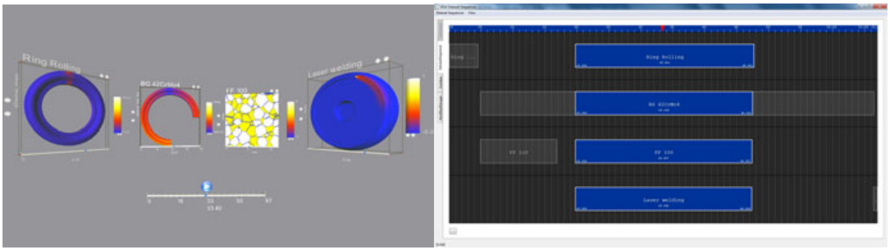

Fig. 10 *left*: 3D visualization scene with local and global virtual time sliders, *right*: abstract 2D view on a sequence

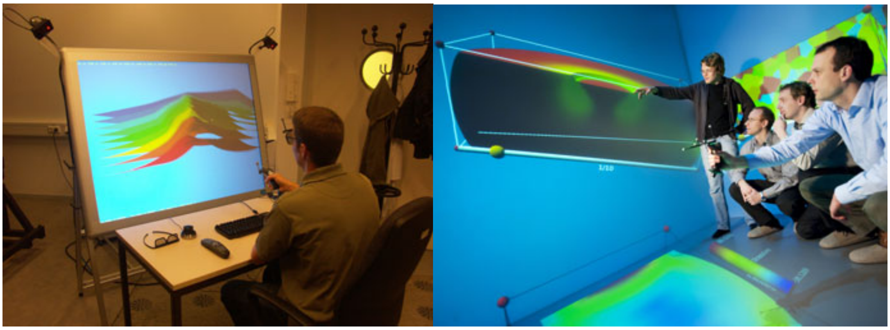

Fig. 11 *left*: midrange VR System, providing head-tracked stereo vision and 6 DOF Interaction, *right*: CAVE-like fully immersive VR System

5.4 Scalability to Heterogeneous Target Display Systems

A core feature of our integrated visualization application is its wide range of target display systems. Based on the ViSTA Virtual Reality Toolkit [vis10, AK08], it can be run on a notebook, a desktop system, a mid-range VR display or on fully immersive multi-display CAVE-like environments (cf. Fig. 11 right).

Thus, the application can be used to interactively analyze data on the desktop, e.g. working in a round-trip manner by tweaking visualization data of a single dataset with ParaView (cf. Sect. 5.1), and then reload the integrated visualization session running in another desktop window or on a mid-range Desktop VR System as seen in Fig. 11 left. The same application can be run on a cluster system that drives a CAVE-like VR System, using the data just prepared on the Desktop. This enables the exploration and analysis of processes with several domain experts interactively (cf. Fig. 11) or can be used to give immersive presentations e.g. to stakeholders, where the remote 2D GUI can serve as a control panel from outside the CAVE or can be literally taken into the CAVE with a Tablet-PC or a similar device.

5.5 Conclusion

The presented IT infrastructure behind the AixViPMaP® enables the coupling of simulation resources at all technical layers from low level distributed scheduling and data transfer up to high-level visual design of simulation chains through a web interface. Data integration assures for data consistency at the syntactical and semantic level. For the visual analysis of the generated simulation data we have given some insights into the special requirements that emerge from visualizing multiple datasets in a common context. With these powerful tools at hand, the AixViPMaP® allows us to explore new ways of investigating simulation data at an inter-simulation tool level.

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Adaptive Information Integration
Bridging the Semantic Gap between Numerical Simulations

Tobias Meisen, Philipp Meisen, Daniel Schilberg, Sabina Jeschke

Abstract The increasing complexity and costs of modern production processes make it necessary to plan processes virtually before they are tested and realized in real environments. Therefore, several tools facilitating the simulation of different production techniques and design domains have been developed. On the one hand there are specialized tools simulating specific production techniques with exactness close to the real object of the simulation. On the other hand there are simulations which simulate whole production processes, but in general do not achieve prediction accuracy comparable to such specialized tools. Hence, the interconnection of tools is the only way, because otherwise the achievable prediction accuracy would be insufficient. In this chapter, a framework is presented that helps to interconnect heterogeneous simulation tools, considering their incompatible file formats, different semantics of data and missing data consistency.

Key words: Application Integration, Data Integration, Simulation Tools, Ontology, Framework

1 Introduction

Within the enterprising environment, the necessity to couple deviating applications being used in a company was recognized early. As a consequence, various concepts were developed that were subsumed under the collective term "Data Integration Techniques" [Whi05]. One of those techniques, "Enterprise Application Integration" (EAI), focuses on integrating business processes based on IT along the value

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chain of an enterprise without taking into account the platform, the architecture as well as the generation of the applications being used in these processes [Con05]. Especially in the widely spread field of enterprise resource planning [Gro10] EAI technologies are well established. These technologies are the foundation for such systems concerning data and application integration. In other fields, e.g. Business Intelligence (BI) or Enterprise Performance Management (EPM), other data integration techniques (i.e. ETL, EII) are mainly used to gain information about cross-applicational business processes [Pan05].

The combination of those integration techniques to analyze more complex business processes, like simulation processes, is seldom taken into account [SP09]. Simulation itself is a well-established field in research and development and different simulations for specific tasks as e.g. casting, welding or cooling and also for whole processes (e.g. transformation or heat-treatment processes) are available. Nevertheless, those simulations have to be seen as isolated applications. They are often specialized for a single purpose (e.g. a specific task) and have neither standardized interfaces nor standardized data formats. Therefore, different results that were received within a simulation can only be integrated into a simulation process if they are checked manually and are adapted to the needs of the subsequent simulations. Current data integration techniques cannot easily be applied to the simulation context because a combination of different techniques and solutions is required. Huge data volumes which are characteristic for simulation processes tend to use ETL techniques, whereby those do not support the important concept of message-oriented transactions. These message-oriented transactions are realized in the field of EAI (e.g. ESB). Although within the field of EAI, huge data volumes cannot be handled satisfactorily. Another problem is the adaption of the data integration process concerning changes within the simulation process (e.g. the integration of a new application, the modification of a simulated object) and the semantics of data that have to be considered by the integration.

In this chapter, a framework will be described which provides the possibility of simulating a production process by making use of existing isolated applications. The integration is based on ontologies, which describe the domain specific knowledge (e.g. material processing simulations) and planning algorithms used to identify how the data can be transferred between different heterogeneous simulation tools. Thereby, the chapter focuses on the integration of data that was generated during applications' usage, whereas the applications' linkup technique, which can be handled with the help of modern middleware [Mye02], will not be stressed.

The framework has been validated on the foundation of the simulation of three production processes, namely a line-pipe, a gear wheel and a top-box. The framework was developed within the project "Integrated Platform for Distributed Numerical Simulation", which is part of the Cluster of Excellence "Integrative Production Technology for High-Wage Countries".

The chapter is structured as follows: In Sect. 2, the current state of technology will be outlined in order to provide a foundation for Sect. 3, in which one of the simulated production processes is exemplarily presented. Section 4 consists of a description of the architecture of the framework that is completed in Sect. 5 by a specification of the used information integration method. Section 6 points out how the framework needs to be extended with regard to the presented use case. In Sect. 7, a conclusion and outlook will be drawn from the insights generated in this chapter.

2 State of the Art

Since the nineties, data integration belongs to the most frequented topics with reference to finding answers to questions which are raised across application boundaries [HRO06]. Today, a multitude of data integration products can be found which are used in different fields of application, whereby each technology can be assigned to one of three techniques [Whi05] (cf. Fig. 1): data propagation, data federation or data consolidation.

With regard to the operational section, data propagation is applied in order to make use of data on a cross-application basis, which is often realized via EAI. As already presented in [Whi05], EAI mainly focuses on small data volumes like messages and business transactions that are exchanged between different applications. In order to realize EAI, a contemporary architecture concept exists, which was developed in connection with service-based approaches [Cha04] and which will be emphasized within this contribution – the so-called Enterprise Service Bus (ESB). The basic idea of ESB, which can be compared to the usage of integration brokers, comprises the provision of services within a system [Sch03]. Within an ESB different services provide a technical or technological functionality with the help of which business processes are supported. A service can be a transformation or a routing service, whereby all services are connected with each other via an integration bus. Transformation services provide general functions in order to transfer data from one format and/or model into another. In contrast, routing services are used to submit data to other services. Both transformation and routing services are used by adapters in order to transfer data provided by the integration bus into the format and the model of an application. Consequently, transformation services support the reuse of implemented data transformations. The advantage of solutions based on ESB is to be seen in the loose coupling of several services, whereas the missing physical data coupling can be regarded as a disadvantage [RD08]: If recorded data has to be evaluated subsequently, it has to be read out and to be transformed once again. According to this fact, a historic or at least long-term oriented evaluation of data is unconvertible, even though such an evaluation is often required.

In order to realize such a unified examination on a cross-data basis, other techniques belonging to the field of data integration need to be taken into consideration (cf. Fig. 1). Data federation, which is studied within the field of Enterprise Information Integration (EII), might serve as one possible solution to enable a unified examination. With the help of EII, data from different data sources can be unified in one single view [BH08]. This single view is used to query for data based on a virtual, unified data schema. The query itself is processed by mediators and divided in several queries fired against the underlying data sources. Because of the fact that

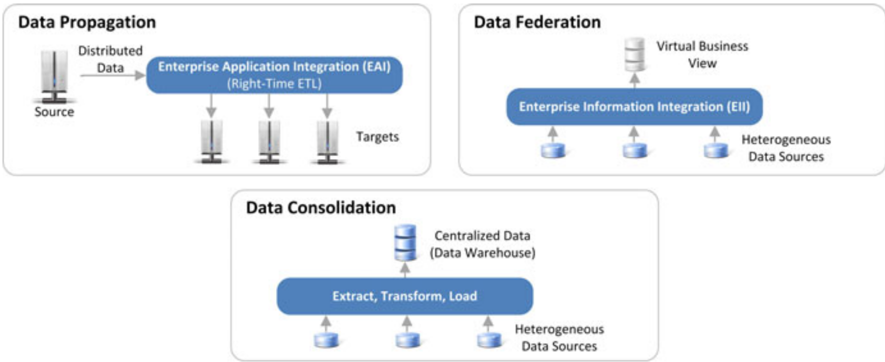

Fig. 1 Main areas of data integration [Whi05]

most EII do not support advanced data consolidation techniques, the implementation will only be successful if the data of the different data sources can be unified, the data quality is sufficient and if access to the data is granted (e.g. via standard query interfaces).

If a virtual view is not applicable, techniques belonging to the field of data consolidation need to be utilized. Data consolidation comprises the integration of differing data into a common, unified data structure. Extract Transform Load (ETL) can be seen as one example for data consolidation, which is often used in the field of data warehousing [VSS02]. ETL starts with the extraction of data from one or several – mostly operational – data sources. The extracted data is than transformed (e.g. joined, modified, aggregated) and the data model is adapted to a final schema (often a so called star schema). During the last phase the data is loaded into a target database (in general a data warehouse).

The presented techniques of data integration have in common that – independent of the technique – the heterogeneity of data has to be overcome. In literature, different kinds of heterogeneity are distinguished [Goh97, KS91, LN07]. In this chapter, the well-established kinds of heterogeneity, technical, syntactic, data model, structural and semantic heterogeneity, listed in [LN07] are considered.

3 Use Case

Within this chapter, the manufacture of a line-pipe will be stressed as example use case. During the manufacture several simulation tools that are specialized for these techniques are used. The goal is the simulation of the whole production process, whereby the results of each specialized tool will be considered across the whole simulation process. The production process which will be used to exemplify the example use case is illustrated in Fig. 2.

The use case starts with a simulation of the annealing, the hot rolling as well as the controlled cooling of the components via the simulation tool CASTS (Access).

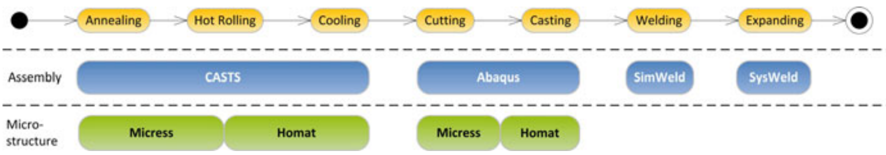

Fig. 2 Production process of a line-pipe (*top*) and the used simulation tools (*middle & bottom*)

The next step consists in representing the cutting and the casting with the help of Abaqus (Dassault Systems), whereas the welding and the expanding of the line-pipe will be simulated via SimWeld (ISF – RWTH Aachen University), and via SysWeld (ESI-Group). Furthermore, the simulation of modifications in the microstructure of the assembly will be realized by making use of Micress and Homat (Access). All in all, the use case contains six different kinds of tools, each based on different formats and simulation models. Thereby, the required integration solution has to take different requirements into account [Sch10]. Two requirements, which turned out to be central with reference to the framework presented in this chapter, are on the one hand, the possibility of data propagation, focusing the semantic data exchange between the applications, and, on the other hand, the necessity of a process-oriented data consolidation. Both are used to facilitate a subsequent visualization and analysis of data collected within the process.

4 Architecture of the Framework

4.1 System Architecture

The framework's architecture is based on the requirements described in Sect. 3. The architecture is depicted in Fig. 3. As illustrated, the framework follows the architecture concept of ESB, whereby the possibility of data consolidation was realized by implementing a central data storage (CDS) [SGH08].

In order to realize a communication (e.g. concerning the exchange of files and overcome the technical heterogeneity) between the integration bus and the different simulation tools, a middleware is used that encapsulates the functionality of routing services which are typical of those used in ESB concepts[1]. Hence, routing services are not considered in this framework, as the integration of a standard middleware is straight forward. The framework is employed with the intention of realizing an integration level, at which service providers, which are directly linked to the integration bus, offer different services. With the help of these services, data can be integrated, extracted and transformed. As the connection is realized via a platform independent messaging protocol, it is not bound to the operating system in use. The employment

[1] Within the use case mentioned in Sect. 3 the application-oriented middleware Condor [CBKB08] is used.

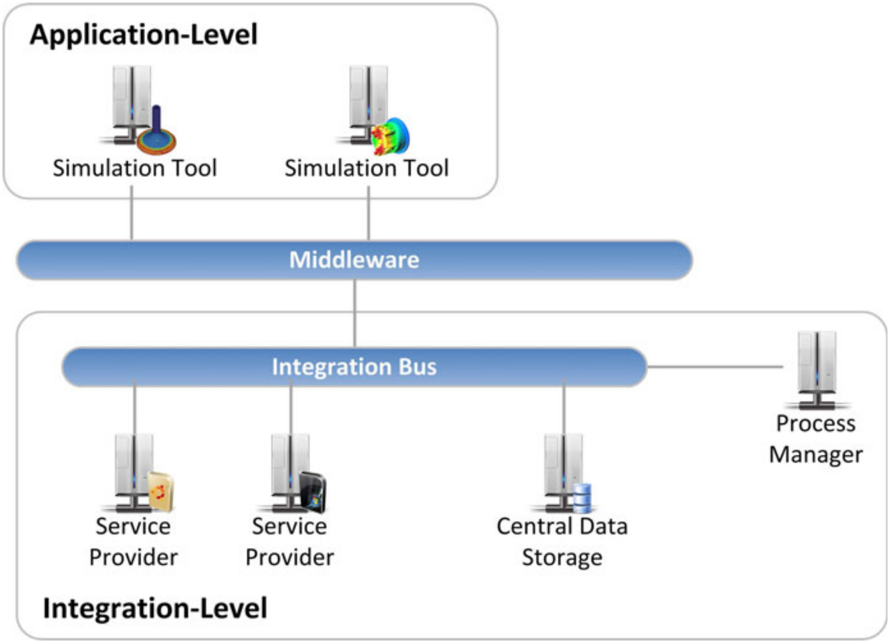

Fig. 3 System-architecture of the framework

of a process manager as well as of a CDS marks an important difference between the architecture described in this section and the architectural pattern of an ESB. The process manager receives all data transferred by the middleware, analyses it and, subsequently, makes it available for each of the service providers via the integration bus. In turn, the service providers tap the required data in order to process it. After a step of processing is finished, the consistency of the data is checked and the next processing step is determined by the process manager.

Consequently, with regards to the processes of data integration and data extraction, the process manager has the task of a central supervisory authority. The service providers as well as the process manager have access to the central data storage, whereby data consolidation and, as a result, analyses of data collected during the process become possible.

4.2 Software Architecture

The framework comprises three main components: the middleware communication, the process manager and the service provider. In order to guarantee a connection between those components, a codebase component is needed, in which a cross-component functionality is encapsulated. In the following, these components will be described in detail.

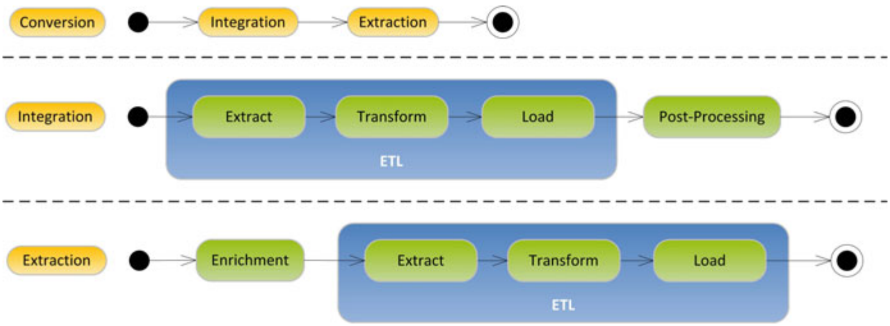

Fig. 4 Service Processes of the framework

4.2.1 Middleware Communication

The Middleware Communication component supports the realization of communication processes between the middleware and the integration bus. It contains adapters, which facilitate the transmission of demands to the integration bus by making use of different communication protocols, such as JMS, RMI or SOAP [KBM08]. As far as a concrete use case is concerned, which is not covered by technologies that were already integrated, the component is modular expandable, which enables the implementation of additional separate adapters (cf. Sect. 5).

4.2.2 Process Manager

The Process Manager comprises the implementation of a management component, which functions as a service provider and a central control unit for integration, extraction and conversion processes. The services provided by this component involve the integration, the extraction and the transformation of data. For each of these services, a service process is stored, which is started and processed as soon as a query is sent to the process manager. A service process describes which services need to be handled with the purpose of providing the requested functionality. The service processes realized within the framework are illustrated in Fig. 4.

The conversion process is defined by an integration process and an extraction process which are both based upon extended ETL process. Within the integration process, a post-processing of integrated data is succeeded, whereas the extraction process makes use of a data enrichment that is carried out prior to the actual ETL process. Thereby, the process manager is used as a mediator with the help of which data is exchanged to those service providers that feature the postulated functionality and capacity. As a consequence, the algorithms, which are important for the process of information integration and which are depending on the use case in question, are encapsulated within the specified service providers. Additionally, the process manager realizes a process-related integration of data. Thereby, the process manager controls the assignment of data to the process step and transmits the context of the process in question to the service providers.

4.2.3 Service Provider

The functionality provided by a service provider always depends on the provided services and therefore on the concrete use case. For instance, the integration of FE data on the one hand and the integration of data of molecular structures on the other hand are based upon different data schemas, even though these processes of integration consist in the same physical object and deal with comparable physical entities.

The framework offers interfaces to common ETL tools as, for example, the Pentaho Data Integrator (PDI) [Lav06]. Thus, the integration and extraction of data, and therefore the overcoming of the syntactical and data model heterogeneity, can be created on the basis of these tools. Furthermore, additional tools can be implemented in order to realize the processes of integration and extraction in the case that this way of proceeding is convenient and necessary within a concrete use case.

Apart from services which provide an ETL process, the framework supports additional services in order to post-process and enrich data. For instance, the post-processing service allows the implementation of plausibility criteria, which need to be fulfilled by the integrated data without reference to their original source. During the process of enrichment, data transformations are carried out with the purpose of editing data stored within the central data store in such a way that the data is able to meet the requirements demanded with regard to the extraction process. Therefore an adaptive information integration process [MSH09] is used, which is described in the next section.

5 Adaptive Information Integration

5.1 Concept

The main goal of the adaptive information integration is to overcome the problems of structural and semantic heterogeneity considering domain specific knowledge. The adaptive information integration is part of the enrichment process step in the extended ETL process being used during the extraction of data. The goal of the process is to extract data in a defined data format, regarding the data model and structure, as well as the semantics, of this format and the domain. Therefore, the implemented enrichment enables the discovery and exploitation of domain specific knowledge. The concept is based upon ontologies and planning algorithms used in the field of artificial intelligence.

First, the existing data is analyzed. The goal of the analysis is the determination of so called features that are fulfilled by the data. A feature is domain specific and expresses structural or semantic properties that are satisfied by the data. Besides, the analysis step determines features that have to be fulfilled by the data to satisfy the requirements of the specific output format. Following the analysis the planning

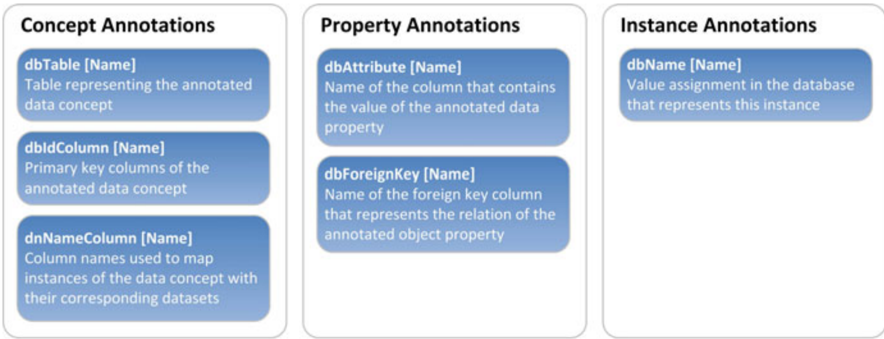

Fig. 5 Ontology annotations

algorithms are used to find a data translation that transforms and enriches the data, so that the enriched data fulfills the features needed by the output format. After the planning is finished, the found data translation is processed. The data transformation algorithms used for the data transformation are realized as a service. The information about the existing transformations and features is expressed in an ontology. The basic structure of this ontology is described in the following section.

5.2 Ontology

The information used by the enrichment process is subdivided among a *framework ontology* and a *domain ontology*. The domain ontology holds information about the concrete transformations, features and applications used in the context of a specific domain. Besides, information about the domain specific data schema is stored. An extract of the domain ontology used to implement the use case is described in Sect. 6, using the Web Ontology Language (OWL).

The *domain ontology* specialize the concepts of the framework ontology in order to specify the conceptualization of the domain. Hence, the framework ontology is a specification of the concepts used in the framework to enable the enrichment process. These main concepts are *data, feature, application* and *transformation*, which are introduced shortly.

The concept *data* is the generalization of all data concepts used in the domain. More precisely each concept in the domain ontology used to describe the data schema of the domain has to be a specialization of the concept *data*. The mapping between data concepts and the data schema of the domain is realized by using a predefined set of annotations. Because of the single mapping between a well-known ontology and a well-known database schema, automatic schema matching algorithms are not used. Instead this approach follows the concept of annotation-based programming. Figure 5 gives an overview of the main annotations.

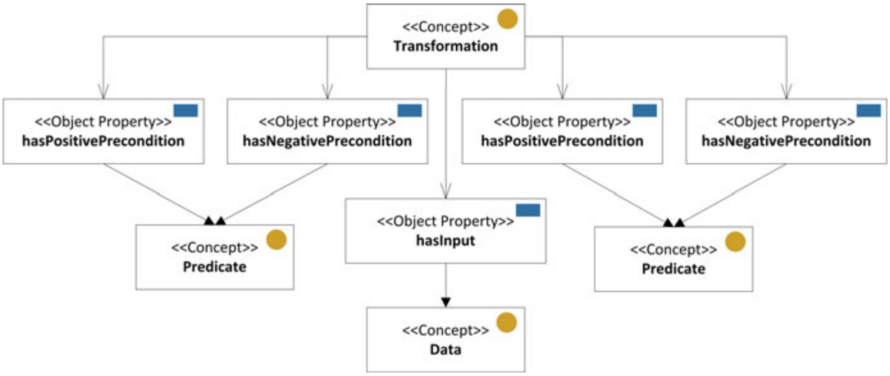

Fig. 6 Fragment of framework ontology – transformation concept

Defining domain specific *features* is done by creating a specialization of the concept feature. Such a specialization is a listing of the requirements that have to be satisfied by a set of data, so that the represented feature is fulfilled.

For each definition of applications and their requirements, instances of the concept *application* have to be expressed in the domain ontology. An instance of the concept *application* can have additional object properties to express domain specific information of an application. Similar to an application, a transformation has requirements that have to be satisfied. Otherwise, the transformation cannot be used. Therefore, each instance of the concept *transformation* has to outline the requirements by defining instances of feature concepts. In addition, a transformation changes the features of data. This is realized by expressing the effects of the transformation in the ontology. The concept *transformation* and its main relations are depicted in Fig. 6.

The input is set by an instance of the concept *data*, whereby the requirements are expressed by instances of either *hasPositivePrecondition* or *hasNegativePrecondition*. These object properties realize relations between the concrete transformation and feature instances. The framework ontology provides a set of logical connectives and quantifiers to express complex requirements like *feature1* **or** *feature2*. Similarly, the effects of the transformation are expressed.

5.3 Components

The concept of the adaptive information integration is realized by three services: the data analyzer, the plan generator and the plan processor. Each service implements one of the previously described steps of the enrichment process.

The data analyzer loads the ontology and establishes a connection to the CDS. By using the domain ontology, the features are determined by querying all defined specializations of the concept *feature*. The implementation of this service makes use of the OWL API [HBHP09] and the reasoner Pellet [SP07]. The fulfillment of a feature is checked by querying once again the CDS. The queries are generated by using the annotation based mapping. The result of the query is analyzed according to the feature definition.

The fulfilled features define the initial state of the data. In addition, the goal state is determined by the data analyzer by reasoning. This means that the current context (required output format and domain specific parameters) is used to query the required features by using the information stored in the domain ontology.

Hence, the result of the data analyzer consists of the initial and the goal state. This information is passed to the plan generator to determine the needed data translation. Therefore, the plan generator queries the existing data transformations from the domain ontology and generates a problem description using the Planning Domain Definition Language (PDDL) [FL03]. The defined planning problem is than solved by a planner component, which generates a solution plan. More detailed, the planner is used to determine a sequence of, so called actions that lead from the initial state to a goal state. The framework supports different planning algorithms like forward, backward and heuristic search, STRIPS algorithm or Planning Graphs [GNT04, HN01]. If the planner succeeds a plan is generated that contains the transformations and their parameterization as well as their ordering to transform the data, so that the required *features* are fulfilled by the data after having processed the plan. Finally, the processing of the plan is realized by the plan processor.

6 Application of the Framework

Within the domain of the use case described in Sect. 3 and the requirements result-ing from the examination of four additional use cases in the domain of FE-simulations, an integration platform has been implemented in parallel to the implementation of the framework. The integrated applications are simulations based upon the finite-element-method. In order to implement the integration platform a domain specific data schema, adapters for integration and extraction, the transformation library and the domain ontology have been provided. In the following, some selected examples will be presented.

6.1 Data Schema

The domain specific data schema has been determined by analyzing the different input and output formats of the simulations used in the use case. Within this data schema, a grid structure, representing the abstraction of the assembly that is simulated, is the central entity. It consists of nodes, cells and attributes. The latter ones exhibit attribute values, which are assigned to individual cells or nodes depending on the class of attributes available in the whole mesh. The integration services, which were specified within the use case, read in the mesh data provided by the simulation, transform it into the central data model and store it into the CDS. In contrast, the extraction services proceed as follows: The mesh data is read out from the CDS and transformed into the required format. Finally, the data is saved into the destination file or into the target database. Because of the prior enrichment, all of the structural and semantic data transformations have been performed. Hence, most of the data transformations formerly performed by the adapter services are omitted.

6.2 Adapter Service

Most of the adapter services have been implemented using the Pentaho Data Integrator (PDI). If more complex data have been given, or binary formats that can only be read by programming interfaces of the manufacturer, either the PDI functionality have been extended using the provided plug-in architecture or the needed functionality has been implemented using Java or C++. For example, the simulation results generated within the simulation tool CASTS are stored in the Visualization Toolkits (VTK) format [SML04]. Hence, an integration service was implemented, which is based on the programming interface provided by the developers of VTK using the provided functionality of the framework. Furthermore, an extraction service was developed with regard to the Abaqus input format, whereby, in this case, the aforementioned ETL tool PDI was used.

6.3 Transformation Library

In order to realize the information integration, different sorts of data transformations for FE data were implemented into the application, for example the conversion of attribute units, the deduction of attributes from those ones that are already available, the relocating of the mesh within space, the modification of cell types (e.g. from a hexahedron to a tetrahedron) or the re-indexing of nodes and cells.

6.4 Domain Ontology

The domain specific information has been expressed in the domain ontology. As described previously in Sect. 5, the domain ontology uses the concept of the framework ontology to express the data schema, the transformations, the applications and the features of the domain. Figure 7 sketches a fragment of the concept *Mesh*.

Within the domain of the use case described in Sect. 3 and the requirements resulting from the examination of four additional use cases in the domain of FE-simulations, an integration platform has been implemented in parallel to the imple-

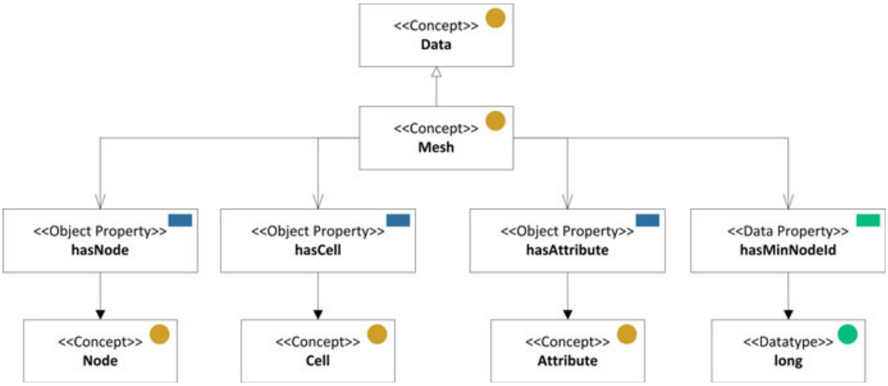

Fig. 7 Fragment of the concept *Mesh* and related concepts

mentation of the framework. The integrated applications are simulations based upon the finite-element-method. In order to implement the integration platform a domain specific data schema, adapters for integration and extraction, the transformation library and the domain ontology have been provided. In the following, some selected examples will be presented.

Because of the number of data and object properties, only a few are depicted. Most interesting is the data property *hasMinNodeId*, which is a sub-property of the *hasMinimumValueProperty*. This kind of data property can be used to prompt the data analyzer to use the SQL *MIN* function, whenever a classification requires such information. Analogous data properties for average and maximum exist within the framework ontology. The depicted object properties *hasNode*, *hasCell* and *hasAttribute* represent the relation between the concept *Mesh* and the concept referred to by the object property. Using the previously described annotations the metadata of the relationship like primary and foreign keys are expressed.

The defined data schema is used to point out different data features of the domain. As described, a feature is a kind of classification of existing data. More precisely, if all conditions of a feature are fulfilled, the data belongs to the concept represented by the feature. One feature is the already mentioned *PlainMeshFeature*. It expresses that a mesh belongs to the class of plain meshes if all nodes of the mesh have a z-coordinate of zero. The feature is illustrated in Fig. 8 as well as expressed by the OWL Manchester Syntax [HP09].

Besides the data schema and the features the ontology also contains information about the available transformations and the used applications. One example of a transformation is *HexaToTetra* that transforms a mesh that is based on hexahedrons into a mesh of tetrahedrons. The transformation searches all occurrences of hexahedrons within the mesh and splits them into tetrahedrons without creating new nodes. Hence, the precondition of the transformation is that at least one hexahedron exists in the mesh. The effect is that all hexahedrons are replaced by tetrahedrons. Preconditions and effects are expressed by using features. The expression of the transformation *HexaToTetra* in the domain ontology is illustrated in Fig. 9.

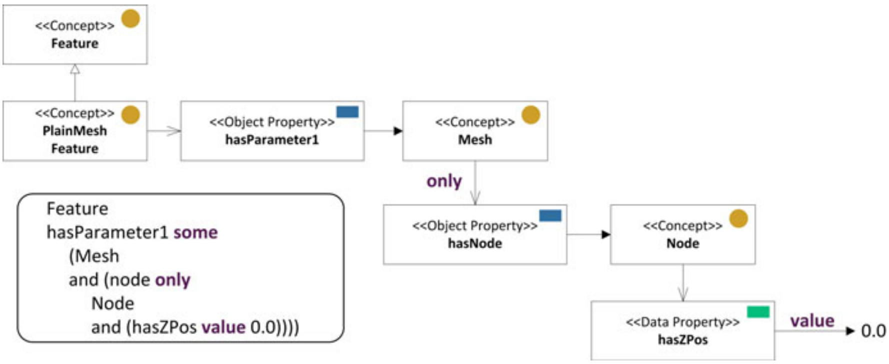

Fig. 8 Expression of the *PlainMeshFeature*

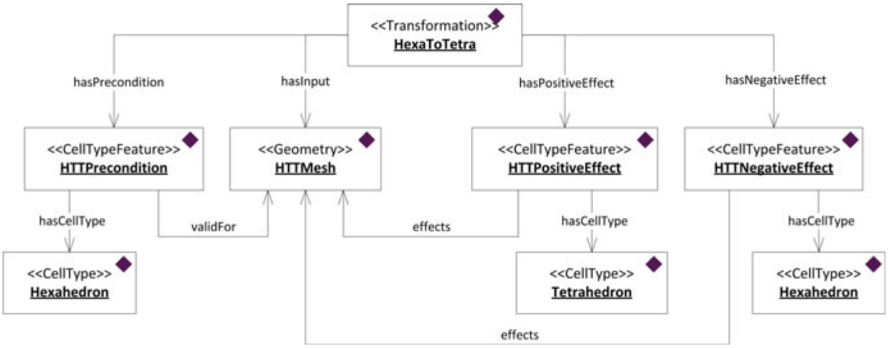

Fig. 9 Expression of the transformation *HexaToTetra*

As described previously a concrete transformation is expressed by an instance of the concept *transformation*, whereby the input, preconditions and effects are expressed by instances of the corresponding concepts. The instance *HTTMesh* of the concept *Mesh* describes that the input of the transformation is some mesh. The precondition is an instance of the concept *CellTypeFeature* expressing that the transformation is only valid if the *HTTMesh* has cells of the cell type hexahedron, which is a concrete instance of the concept *CellType*. Also, the effects are expressed using *CellTypeFeature*. The positive effect is that the resulting mesh contains cells of the type tetrahedron, whereas the negative effect is, that the concrete *CellTypeFeature* representing the hexahedron is forfeited.

6.5 Example

Concluding this section, a small example of the data provision of results generated by the simulation CASTS to the simulation Abaqus is presented. The example fo-

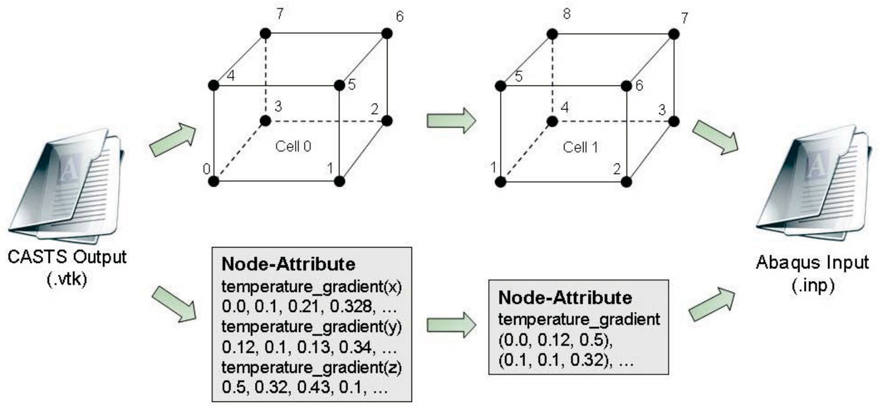

Fig. 10 Simplified illustration of the resulting data translation from CASTS to Abaqus

cuses on the structural changes of the data that are needed, in order to enable the usage of the data in Abaqus. Using the VTK data format, the indexing of nodes and cells begins with zero. Instead, Abaqus requires a sorted indexing starting with one. Additionally, in CASTS, vectors are decomposed into single components and stored as attribute values assigned to nodes, whereas in Abaqus, vectors need to be quoted entirely. Due to the data enrichment, the needed data transformations have been determined autonomously (cf. Fig. 10).

7 Conclusion

The development of the framework presented in this chapter can be regarded as an important step in the establishment of integrated simulation processes using heterogeneous simulations. Both, data losses as well as manual, time-consuming data transformations from one data format to another are excluded from this approach. The suggested framework facilitates the interconnection of simulation tools, which were – until now – developed independently and which are specialized for certain production processes or methods. Furthermore, the integration of data generated in the course of the simulation is realized in a unified and process-oriented way. Apart from the integration of further simulation tools into an application, which was already established, it is essential to extend the domain of simulations reflected upon with additional simulations covering the fields of machines and production. In this way, a holistic simulation of production processes is provided. Thereby, a major challenge consists in generating a central data model, which provides the possibility of illustrating data uniformly and in consideration of its significance in the overall context, which comprises the levels of process, machines as well as materials. Due to the methodology presented in this chapter, it is not necessary to adapt applications to the data model aforementioned. On the contrary, this step is realized via the integration application, which is to be developed on the basis of the framework. Because of the unified data view and the particular logging of data at the process level, the framework facilitates a comparison between the results of different simulation processes and those of simulation tools. Furthermore, conclusions can be drawn much easier from potential sources of error – a procedure which used to be characterized by an immense expenditure of time and costs. The realization of this procedure requires the identification of Performance Indicators, which are provided subsequently within the application. In this context, the development of essential data exploration techniques on the one hand and of visualization techniques on the other hand turns out to be a further challenge. Concepts and methods focusing this challenge will be developed and summarized under the term *Virtual Production Intelligence*. This term is motivated by the notion of *Business Intelligence*, which refers to computer-based techniques used to handle business data in the aforementioned manner.

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A Framework for Adaptive Data Integration in Digital Production

Tobias Meisen, Rudolf Reinhard, Daniel Schilberg, Sabina Jeschke

Abstract Modern production processes' complexity increases steadily. Therefore, virtual planning has been prevailed as a method used to evaluate risks and costs before the concrete realization of production processes. In doing so, virtual planning uses a number of numerical simulation tools that differ in the simulated production techniques as well as in the considered problem domains. Users may choose between tailor-made, thus costly, simulation tools delivering accurate results and off-the-shelf, thus less costly, simulation tools causing post-processing efforts. Thereby, simulating a whole production process is often hardly realizable due to insufficient prediction accuracy or the missing support of a production technique. The supposed solution of interconnecting different simulation tools to solve such problems is hardly applicable as incompatible file formats, mark-up languages and models describing simulated objects cause an inconsistency of data and interfaces. This paper presents the architecture of a framework for adaptive data integration that enables the interconnection of such numerical simulation tools of a specific domain.

Key words: Semantic Information Integration, Ontology, Service-Oriented-Architecture, Semantic Services

1 Introduction

The increasing complexity of modern production processes requires their simulation before they can be implemented into a real environment. Besides, the requirement of a lasting optimization in production processes is best achieved by making use of simulations [BB99, ZVG+95]. Because of high costs and time needs, it is hardly possible to realize such simulations or optimizations by experiments repre-

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senting the complete production process. Hence, the usual approach to realize these with minimized experimental effort consists in the use of computational simulation tools. Unfortunately, because of the highly specific types of these simulation tools, the underlying models are heterogeneous and therefore incompatible in most cases. Furthermore, these tools mostly regard single aspects of the production process, like heat treatment or welding aspects, and do not consider information gained from simulation results of previous steps. Consequently, interactions of effects on different scales are oversimplified or conditionally included in the used simulation models (e.g. material models). Thus, it is necessary to manually link the simulations by creating translation tools and providing the needed infrastructure. In the field of simulations, the process development time using manually linked simulations incurs an overhead of 60 % solely caused by the manual operation of the individual simulation components and translation tools of a simulation chain [Lan03]. Hence, to benefit from the simulation, it is necessary to realize the interconnection in a semi-automatic way.

Facilitating such an interconnection of highly interdependent models firstly requires the identification and assessment of the character of interdependencies between the models. Secondly, translators considering these interdependencies and facilitating the interconnection between these models have to be created and thirdly, the degree of data resolution necessary for adequately representing the interdependencies has to be adjusted. Because the simulation model and its outcome highly depend on the concrete data, such a translator has to consider the data structure as well as its instantiation at runtime.

In this paper, a framework is presented that uses adaptive data integration to provide base implementations of methods and structures that facilitates the interconnection of heterogeneous simulation tools. In contrast to existing solutions, the framework and its translators use domain-specific knowledge for realizing the interconnection. It has been successfully adopted to implement the AixViPMaP® (Aachen (Aix) Virtual Platform for Materials Processing) [SP09].

The paper is structured as follows: In Sect. 2, the current state of the art will be outlined in order to provide a foundation for the following sections. Subsequently, an overview of a concrete case study of the framework will be described in Sect. 3 that will be used to explain the framework as well as the underlying technologies and methods. Section 4 gives an insight into the architecture of the framework, whereas Sect. 5 focuses on the adaptive data integration. In Sect. 6, a conclusion and an outlook will be drawn from the insights generated in this paper.

2 State of the Art

Integration problems belong to the most frequented topics with reference to finding answers to questions which are raised across application boundaries [HRO06, Whi05]. The complexity of such integration problems, in particular in the domain of simulation tools, arises by reason of the many topics that have to be regarded to provide a solution: Besides application interconnection on the technical level, the data has to be propagated and consolidated. Furthermore, user interfaces are required to model the underlying process and to visualize the data for the purpose of analysis. In addition, the integration of data requires the knowledge and thus the comprehension of the underlying processes on a domain expert's level. Because of those reasons, integration solutions are often specialized and highly adapted to the specific field of application. One example of such a solution is the Cyber-Infrastructure for Integrated Computational Material Engineering (ICME) [Hau10] concerning the interconnection of MATLAB applications. Other examples are solutions that require the making of adjustments on the source level of the application, like CHEOPS [SYvWM04] or the FlowVR toolkit [AR06]. Yet others require the implementation of standards like SimVis [Kal07]. Realizing a flexible solution, the technical, the data and the semantic level have to be taken into account.

On the technical level, simulation tools are special software components that run on corresponding hardware resources. Starting with remote procedure calls (RPC) [RG04], the Common Object Request Broker Architecture (CORBA®) [Hen08], web services and concepts like service-oriented architectures (SOA) [Nat03] or ones specific to grid computing such as the open grid services architecture (OGSA) [Fea05], there are currently a number of different concepts at various levels of abstraction for creating a distributed software architecture. Hence, the whole area of "simulation coupling" presents a heterogeneous landscape of concepts and different views as to what is meant by "simulation coupling".

On the data and on the semantic level, different research areas are working on the raised problems and promising contributions have been provided in the last decades. Application integration is concerned with the development and evaluation of methods and algorithms that allow application functionalities to be integrated along processes [Con06, GTT03]. Information integration, in turn, deals with the evaluation of methods and algorithms that can be used to merge information from different sources [HRO06, Vis04]. Data warehouses are a popular example of the use of information integration methods. Another example is the information integration of meta-search engines, which gather and display information from numerous search engines. Both application and information integration, have in common that they can only be successful if the heterogeneity between the pieces of information or applications that are shared can be overcome. A variety of preliminary studies have identified different heterogeneity conflicts [Gag08, GSC95] that can be generally classified as syntactic, structural or semantic. In the past, a variety of methods and algorithms have been developed to overcome these conflicts. In particular, the definition of data exchange standards is often proposed as one possible solution. In the field of production technology, numerous standards have been introduced including the *Initial Graphics Exchange Specification (IGES)* developed in the United States, the French standard for data exchange and transfer *"Standard d'Exchange et de Transfer (SET)"* and the German neutral file format for the exchange of surface geometry within the automobile industry "Verband Deutscher Automobilhersteller – Flächen-Schnittstellen (VDAFS)" [ES05]. Such standards are usually limited to specific disciplines and this inhibits all-embracing, cross-disciplinary integration. In turn, the Standard for the Exchange of Product Model Data (STEP) aims at the definition of a standard that is not limited to specific disciplines [AJA+00]. Such standards are characterized by complex specifications and by a slow realization of necessary adjustments [Con06]. Although the complexity is often not needed by specific disciplines, it is essential for the realisation of the interconnection as the standard needs to be supported by each tool.

More promising solutions developed within the last years have been results of research projects involving semantic technologies. The already mentioned Service-Oriented-Architecture (SOA), which is an essential model for developing software out of reusable and distributed services [Erl08], might serve as an example. SOA has been commonly lauded as a silver bullet for application integration problems [Kra10, DFHP10]. In traditional scenarios, where workflow and business processes rely on syntactically specified and fix processes, services have been a way to facilitate a loose coupling between interacting services using adaptors or mediators as translators between different models and formats. Thereby, as already described, it requires substantial manual effort to define such adaptors and mediators. Semantic Web Services have been a proposal to provide formal declarative definitions of the semantics of services and to facilitate a higher level of automation in using services [DFHP10]. However, such approaches are in need of semi-automated and automated concepts to search and locate services as well as to select and compose them to handle a given task (e.g. the translation of data, so that it can be used by another simulation). Thereby, semi-automatic or automatic service composition requires information about the service's semantics and the used data structures. Several conceptual models [vdA03] like SAWSDL [KVBF07], WSDL-S, WSMO and OWL-S to describe the semantics of a service and frameworks like WSMX [HCM+05] and METEOR-S [Ver05] to provide the base functions for discovery, selection, ranking, composition, orchestration and invocation of services have been proposed. However, many scenarios (cf. Sect. 3) require the consideration of conditions during service composition that are only knowable at runtime. Hence, common solutions for service selection cannot be employed. Instead, the framework uses a similar approach as presented in [PLM+10] facilitating the replacement or the selection of services that fit in a current context. Therefore, the traditional approach, which comprises the modifying of process models with branches mapping all possible contexts, becomes unnecessary.

3 Case Study

As described in Sect. 1, the aim of the framework is to provide a generic, flexible solution for interconnecting heterogeneous numerical simulations so that the simulation of whole production processes becomes possible. In this section, an example scenario is described that will be used in the following sections to explain the architecture as well as the underlying technologies and methods. The example is an extract of the scenarios implemented in the AixViPMaP®.

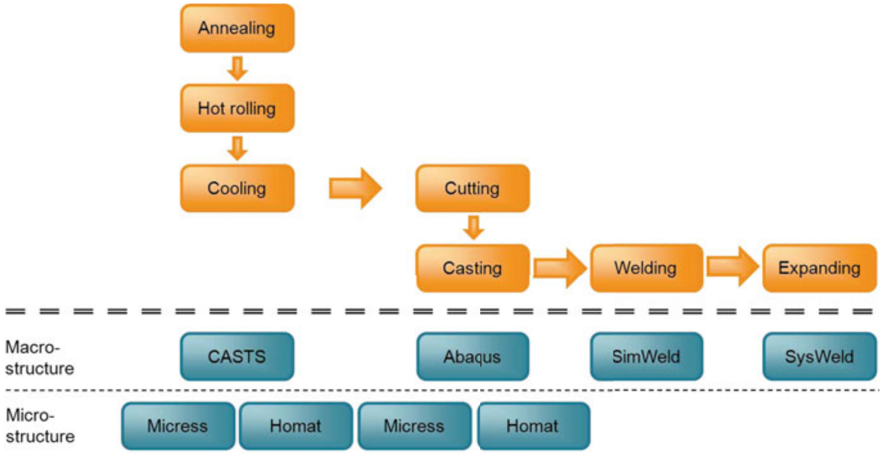

Fig. 1 Simulation process and simulation tools

In the test case, the production process of a line pipe focusing on the material models using different heterogeneous simulation tools has been the object of consideration. The simulation has to consider the macro- and the micro-level. The process and the involved simulation tools are depicted in Fig. 1.

The simulation process starts with the simulation of the annealing, the hot rolling as well as the controlled cooling using the software tool CASTS. In the next step, the cutting and the casting of the line pipe are simulated with the aid of Abaqus. The welding and the expanding of the line-pipe are simulated via SimWeld, a tool which has been developed by the Welding and Joining Institute (ISF) of the RWTH Aachen University, and via SysWeld, a software product contrived by the ESI-Group [RM07]. Furthermore, the simulation of modifications in the microstructure of the assembly will be realized by making use of Micress [LNS98] and Homat [LA10], which were both developed by Access e.V.

All simulation tools that are employed on the macro level are based upon the finite element method. Hence, each tool requires a finite element model as input enriched by tool-specific configuration data. In the following, it is described how the translation process between the models of the simulation tools Abaqus and SimWeld can be realized and how it depends on the instantiation of the finite element model. Two example translation processes are visualized in Fig. 2.

Both Abaqus and SimWeld use different start indexes to uniquely indicate the nodes and elements of the finite element model. In addition, the labelling of spatially resolved properties differs (e.g. temperature). Hence, the translation process has to resort the indices of the nodes and the elements and it has to rename the labelling of relevant properties. More complex is the handling of the element topology. Because SimWeld does only support hexahedrons as element topology, the given finite element model has to consist of elements of this type or it has to be translated by the translation process. In the case of tetrahedrons, such a translation cannot be realized

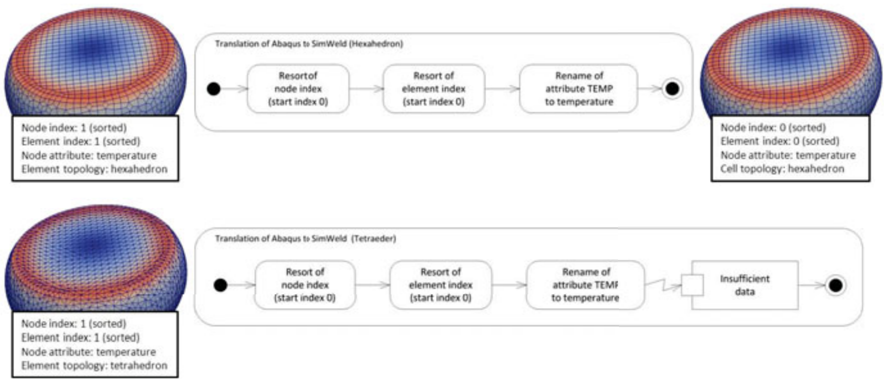

Fig. 2 Translation process for different cell topologies

without making use of remeshing methods. For this example, it is assumed that such a remeshing is not available. Hence, the translation cannot be realised for such an initial state.

In traditional approaches, a translation process for each possible initial and target state would be deployed. Unknown states could not be handled, even if the needed transformation would be available. Hence, instead of using the traditional approach, the framework uses semantic technologies to identify the initial and the target state and to identify the required translation process.

4 Architecture

The architecture of the framework is based upon a message-oriented approach. Thereby, messages are employed to facilitate the communication between the services by making use of a message bus. A message contains all information that is necessary to execute a service. This includes the message header containing technical data like information about the sender and the receiver as well as the message body that involves data semantically related to the simulation tool that has created the data. Following the example (cf. Sect. 3), the input and the output data of the simulation tools are written into different data files. Hence, the message body has to contain information about the location of such files.

Messages are exchanged by services following a defined process, whereby the process does not determine which service has to be executed. Instead, the framework executes a generic translation process each time a simulation tool produces data that have to be used by another simulation tool. The translation process focuses on the translation of the different kinds of data by considering the target format and, optionally, the storage of data for a continuous analysis after the simulation process has been finished completely. Hence, a central functionality of the framework is to provide and to monitor such generic translation processes. A translation process has

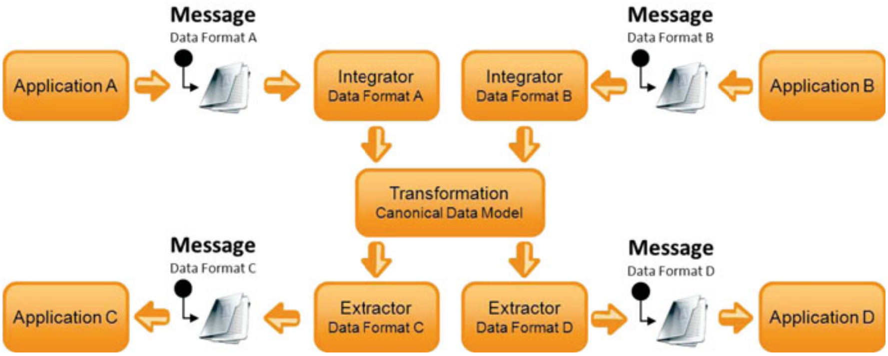

Fig. 3 Service-oriented translation process

to be able to resolve differences between the supported data formats. If numerous applications had to communicate with each other, such a generic translation process would have to consider each possible pair of applications, which would in turn result in a high complexity of such a process. The complexity can be reduced by dividing the required functionality into different services and by introducing a so-called Canonical Data Model [Hoh04]. Such a model provides an additional level of indirection between applications' individual data formats. Following the service-oriented approach, a translation process can then be described by composing three types of services: a service for integrating data into the Canonical Data Model, which is called Integrator, a service for extracting data from the Canonical Data Model, which is called Extractor, and a service to transform the data in such a way that it can be extracted. Figure 3 summarizes this approach.

The concrete Integrator and Extractor have to be specified during runtime as the concrete simulation process is not known previously. Hence, the Integrator and the Extractor can be defined as so-called service templates [PLM$^+$10]. The transform service is more complex than the Integrator and the Extractor and cannot be described by a service template. Instead, the transformation of data itself requires the composition of concrete services, whereby, unlike the generic translation process, the required service templates are unknown to the greatest possible extent. The determination of the service composition and the execution is the main functionality of the adaptive data integration, which is outlined in detail in Sect. 5. The described functionality is summed up by the integration layer of the framework.

Besides the translation of data, the framework comprises another functionality required to facilitate the linking and the execution of the simulation tools on the technical level. As described in Sect. 2, a wide range of solutions has been focused by the research. Instead of selecting one solution, the framework facilitates the usage of different solutions considering the domain-specific requirements. Therefore, a gateway [Hoh04] is used that connects the selected middleware to the integration layer. The gateway extends the middleware functionality, namely the interconnection of different simulation resources, by functions that facilitate a message-oriented

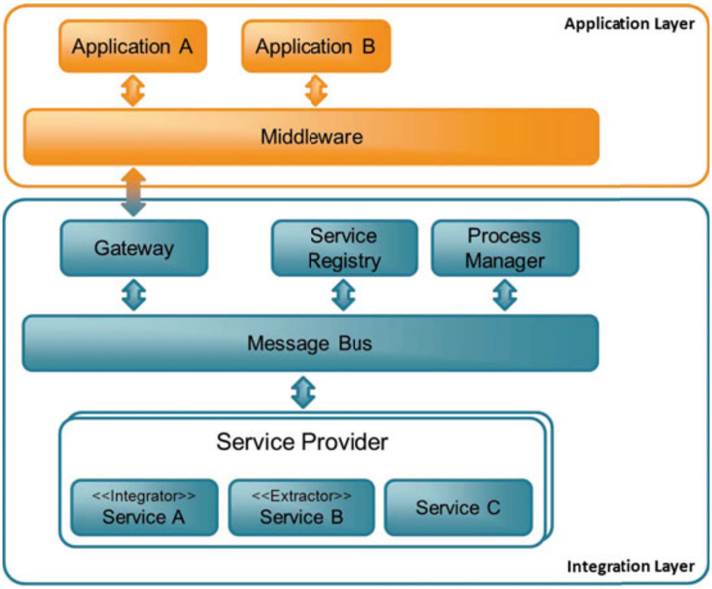

Fig. 4 Architecture of the framework

communication. Within the AixViPMaP®, a gateway for the application-oriented middleware Condor [CBKB08] has been implemented and integrated into the framework. Summarized, the architecture of the framework is depicted in Fig. 4.

The figure extends the previously described layers and components by a service registry, a service provider and a process manager. The service registry is a central service used to find, register and unregister service providers and their corresponding services. The service provider is a collection of different services and facilitates the overcoming of the technical heterogeneity between the message bus and concrete services. It contains service activators [Hoh04] for different service protocols like the web protocols SOAP and WSDL and implements required functionality like the registration in the service registry. Hence, concrete service implementations do not have to implement any specific interfaces to work within the framework. The process manager provides the functionality to monitor and to execute translation processes. It triggers the Integrator and the Extractor services as well as the adaptive data integration.

5 Adaptive Data Integration

The adaptive data integration focuses on the automated determination of a service composition considering the current context of data. The main goal is to overcome the structural and semantic heterogeneity by considering domain-specific knowl-

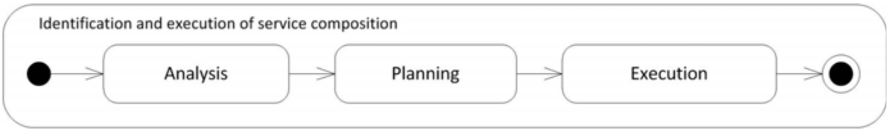

Fig. 5 Process for service composition and execution

edge so that the data can be handled by an extraction service. Thereby, an extraction service does not contain any validation or transformation steps, with the exception of syntactical transformations (e.g. number format). Instead, the adaptive data integration supports the extraction service with regard to the extraction of data and the loading of it into the desired format without being dependent on a complex rule-based translation process. The determination of the required service composition is realized within three steps (cf. Fig. 5).

First, the existing data is analysed. The goal of the analysis is the determination of so-called features that are fulfilled by the data. A feature is domain-specific and expresses a structural or semantic property that is satisfied by the data. In addition, the analysis step determines features that have to be fulfilled by the data to satisfy the requirements of the specific output format. Second, following the analysis step, planning algorithms are used to find a data translation process that transforms and enriches data in such a way that the transformed data fulfils the requested features. After the planning is finished, the determined service composition is executed in a third step. The transformation algorithms are realized as services. Hence, they are loosely coupled and can be run in a distributed environment. In the following, the different process steps are described in detail.

The analysis step serves the purpose of evaluating a given set of data and of identifying domain specific features fulfilled by this set. It is implemented into a so-called Analyser service that represents, similar to the Integrator and Extractor service, a template for services with such functionalities. Therefore, first of all, the structure and the semantics of the data have to be specified in a formal, explicit specification so that this information can be consulted by the analysis. In addition, the features that have to be evaluated have to be specified in a similar way. Following the example presented in Sect. 3, possible features are the cell topology of the finite element model, properties of the node and the element index, like the starting number, or the dimensionality of the data. The presented approach makes use of the Web Ontology Language (OWL) [W3C09] to specify the features and the data structure with the help of ontologies. Figure 6 illustrates an excerpt of the data structure ontology.

By making use of ontologies, the fulfilment of a feature can be determined by reasoning. Because of the huge amounts of data that have to be analysed, the framework contains a so-called ontology-based analyser. Similar to the KAON2 reasoner [MS06], it supports the definition of mappings between the data structures specified in the ontology and a relational data model. However, instead of defining the mapping in a separated configuration file, this analyser supports ontology-

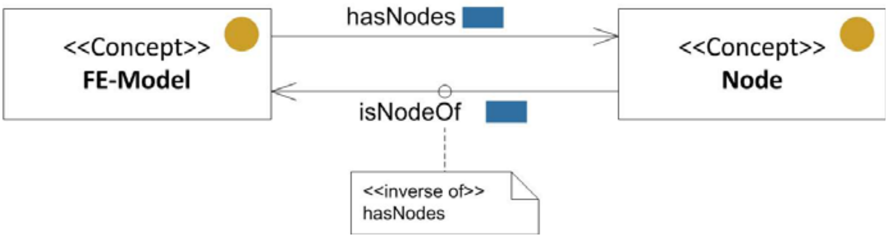

Fig. 6 Example of data structure conceptualisation

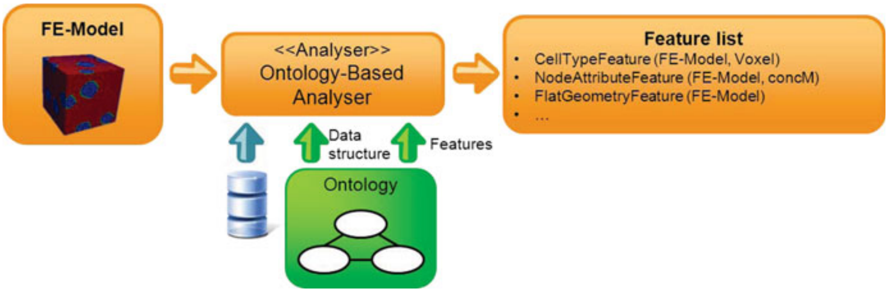

Fig. 7 Annotations for data structure conceptualisation

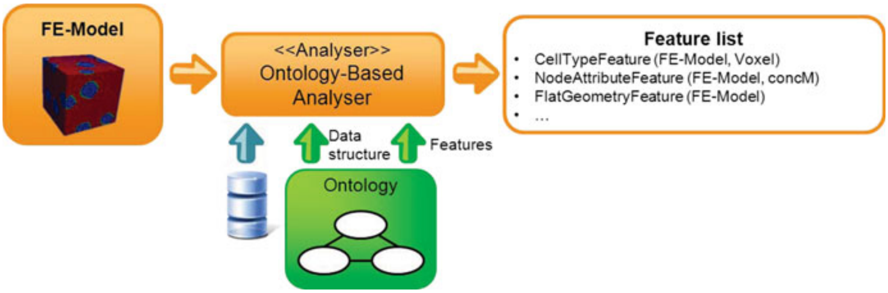

Fig. 8 Example of the ontology-based analyser service

annotations. Hence, instead of being limited to the KAON2 reasoner, different reasoners can be used. Figure 6 shows the example depicted in Fig. 7 extended by annotations.

The ontology-based analyser employs this information to evaluate the given data. Until now, the analyser only supports relational database and the query language SQL. Figure 8 depicts the concept of the ontology-based analyser.

Subsequent to the analysis, the planning step is executed. The aim of this step is to identify a composition of available transformation services that transforms and enriches the data in such a way that the requirements of the subsequent Extractor service, defined by a feature list, are fulfilled by the data. The approach makes use of SAWSDL (Semantic Annotations for WSDL and XML Schema) [KVBF07]

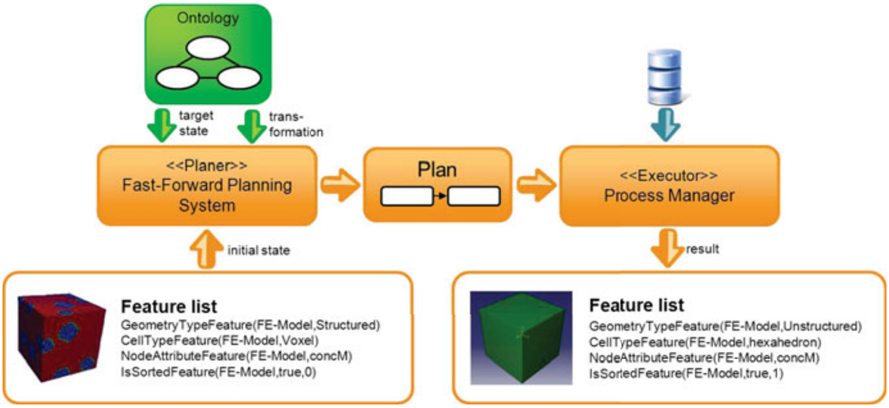

Fig. 9 Example of planning and execution

to specify the services' semantics. The preconditions and effects of the different transformation services are formally specified in OWL ontologies. The result of the planning is the required translation process that is finally executed by the process manager. The process is exemplarily visualized in Fig. 9.

For the realisation of the planning, the fast-forward planning system [Hof01], which has been integrated into the framework, is used. In the example formerly presented within this paper, the initial mesh is structured and consists of voxel elements. In addition, it has a node property named 'concM'. The indexing of the nodes and elements is closed, which means there are no gaps in the numbering of the index, starting with zero. For extracting the data into the desired target format, the mesh has to fulfil a set of features defined in the target state. These features determine that the mesh has to be unstructured and that it consists of hexahedrons. Besides, the indexing of nodes and elements has to be closed and started by one. Hence, the planning algorithm would determine a plan that contains three steps. First, the structured mesh would be transformed into an unstructured one. Second, the cell topology would be translated from voxel to hexahedron and at least, the node and element indices would be resorted so that they start by one.

6 Conclusion

In this paper, the architecture of a framework which facilitates the interconnection of heterogeneous numerical simulations has been presented. In the process, adaptive data integration assures data consistency at the syntactical, structural and semantic level. The framework has been successfully used to implement the AixViPMaP®, which allows new ways of exploration and investigation of simulation data at an inter-simulation tool level.

As presented, the complexity of the researched case study is determined by the complex data structures and semantics that have to be analysed to find appropriated services. The framework handles this complexity by providing the concept of adaptive data integration. This facilitates the analysis of data and the determination of features that are used to define the requirements of each simulation tool. By describing the set of features that are changed by a transformation service, the framework supplies analysis, planning and execution services to identify if a translation process exists and how it has to be executed in case of its existence.

Currently, the framework focuses on the problem of data heterogeneity and does not consider additional information like the Quality of Service (QoS) to evaluate a determined translation process. In the future, the framework could be extended by such aspects. Promising solutions for QoS can be found in [XWKB10, AKLR09]. However, because the framework is currently not to be used in open environments, the consideration of quality aspects is not the main focus.

Instead, the framework will be extended by an analysis layer to provide a complete solution for simulation interconnection and integrated analysis – a so-called Virtual Production Intelligence solution.

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Application Integration of Simulation Tools Considering Domain Specific Knowledge

Tobias Meisen, Philipp Meisen, Daniel Schilberg, Sabina Jeschke

Abstract Because of the increasing complexity of modern production processes, it is necessary to plan these processes virtually before realizing them in a real environment. On the one hand there are specialized simulation tools simulating a specific production technique with exactness close to the real object of the simulation. On the other hand there are simulations which simulate whole production processes, but often do not achieve prediction accuracy comparable to the specialized tools. The simulation of a production process as a whole achieving the needed accuracy is hard to realize. Incompatible file formats, different semantics used to describe the simulated objects and missing data consistency are the main causes of this integration problem. In this paper, a framework is presented that enables the interconnection of simulation tools of production engineering considering the specific knowledge of a certain domain (e.g. material processing). Therefore, an ontology-based integration approach using domain specific knowledge to identify necessary semantic transformations has been realized. The framework provides generic functionality which, if concretized for a domain, enables the system to integrate any domain specific simulation tool in the process.

Key words: Application Integration, Data Integration, Simulation Tools, Ontology, Framework

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1 Introduction

Within the enterprising environment, the necessity to couple deviating applications being used in a company was recognized early. As a consequence, various concepts were developed that were subsumed under the collective term "Data Integration Techniques" [Whi05]. One of those techniques, "Enterprise Application Integration" (EAI), focuses on integrating business processes based on IT along the value chain of an enterprise without taking into account the platform, the architecture as well as the generation of the applications being used in these processes [Con06]. Especially in the widely spread field of enterprise resource planning [Gro10] EAI technologies are well established. These technologies are the foundation for such systems concerning data and application integration. In other fields, e.g. Business Intelligence (BI) or Enterprise Performance Management (EPM), other data integration techniques (i.e. ETL, EII) are mainly used to gain information about cross-applicational business processes [pan].

The combination of those integration techniques to analyse more complex business processes, like simulation processes, is seldom taken into account [SP09]. Simulation itself is a well-established field in research and development and different simulations for specific tasks as e.g. casting, welding or cooling and also for whole processes (e.g. transformation or heat-treatment processes) are available. Nevertheless, those simulations have to be seen as isolated applications. They are often specialized for a single purpose (e.g. a specific task) and do neither have standardized interfaces nor standardized data formats. Therefore, different results that were received within a simulation can only be integrated into a simulation process if they are checked manually and are adapted to the needs of the subsequent simulations. Current data integration techniques cannot easily be applied to the simulation context because a combination of different solutions is required. Huge data volumes which are characteristic for simulation processes tend to use ETL solutions, but a message-oriented transaction is not supported. This message-oriented approach is realized in the field of EAI solutions (e.g. ESB), although within this field, huge data volumes cannot be handled satisfactory. Another problem is the adaption of the data integration process concerning changes within the simulation process (e.g. the integration of a new application, the modification of a simulated object) and the semantics of data that have to be considered by the integration.

In this paper, a framework will be described which provides the possibility of simulating a production process by making use of existing isolated applications. The integration method uses ontologies to describe the domain specific knowledge (e.g. material processing simulations) and planning algorithms to identify how the data can be transferred between different heterogeneous simulation tools. Thereby, the paper focuses on the integration of data that was generated during the applications' usage, whereas the applications' linkup technique, which can be handled with the help of modern middleware [Mye02], will not be stressed.

The framework has been validated on the foundation of three production process simulations. A line-pipe, a gear wheel and a top-box production process were simulated, whereby each process consists of up to six different simulation tools. The framework was developed within the project "Integrated Platform for Distributed Numerical Simulation", which is a part of the Cluster of Excellence "Integrative Production Technology for High-Wage Countries".

The paper is structured as follows: In Sect. 2, the current state of technology will be outlined in order to provide a foundation for Sect. 3, in which one of the simulated production processes is presented. Section 4 consists of a description of the architecture of the framework that is completed in Sect. 5 by a specification of the used data integration method. Section 6 points out how the framework needs to be extended with regard to the presented use case. In Sect. 7, a conclusion and outlook will be drawn from the insights generated in this paper.

2 State of the Art

Since the nineties, data integration belongs to the most frequented topics with reference to finding answers to questions which are raised across application boundaries [HRO06]. Today, a multitude of data integration products can be found which are used in different fields of application, whereby each technology can be assigned to one of three techniques [Whi05] (cf. Fig. 1):

- Data Propagation
- Data Federation
- Data Consolidation.

With regard to the operational section, data propagation is applied in order to make use of data on a cross-application basis, which is often realized via EAI. As already presented in [Whi05], EAI mainly focuses on small data volumes like messages and business transactions that are exchanged between different applications. In order to realize EAI, a contemporary architecture concept exists, which was developed in connection with service-based approaches [Cha04] and which will be emphasized within this contribution – the socalled Enterprise Service Bus (ESB). The basic idea of ESB, which can be compared to the usage of integration brokers, comprises the provision of services within a system [Sch02]. Figure 2 illustrates the schematic structure of an ESB.

Within an ESB different services provide a technical or technological functionality with the help of which business processes are supported. A service can be a transformation or a routing service, whereby all services are connected with each other via the integration bus. Transformation services provide general functions in order to transfer data from one format and/or model into another. In contrast, routing services are used to submit data to other services. Both transformation and routing services are used by adaptors in order to transfer data provided by the integration bus into the format and the model of an application. Consequently, transformation services support the reuse of implemented data transformations. The advantage of a solution based on ESB is to be seen in the loose coupling of several services, whereas the missing physical data coupling can be regarded as a disadvantage [RD08]: If

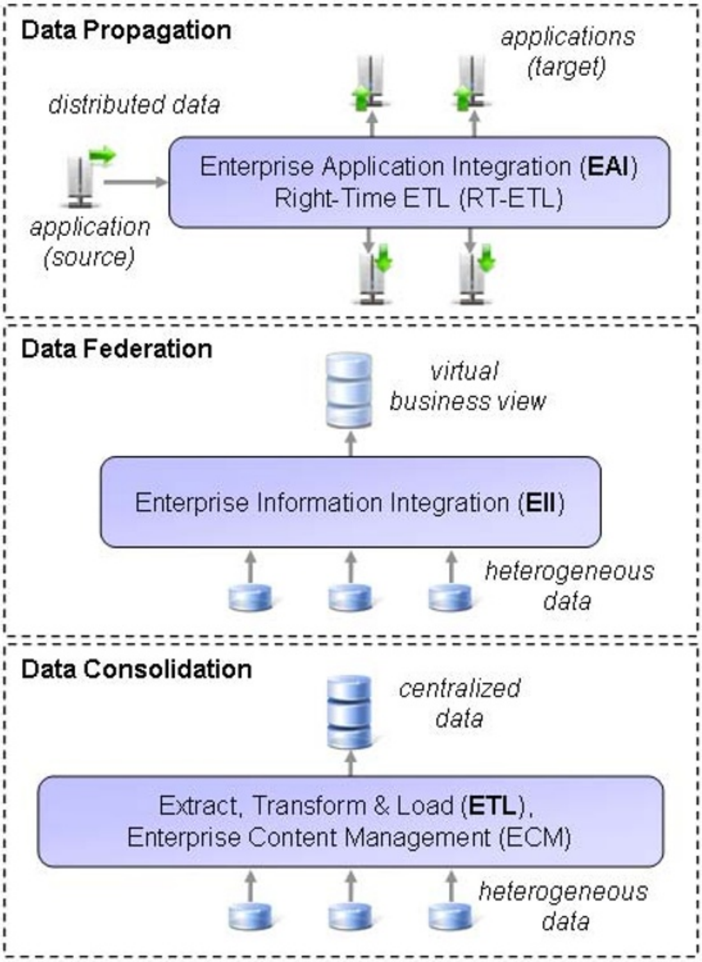

Fig. 1 Main areas of data integration [Whi05]

recorded data has to be evaluated subsequently (e.g. with the help of data exploration techniques like OLAP or Data Mining), it has to be read out and to be transformed once again. According to this fact, a historic or at least long-term oriented evaluation of data is unconvertible, even though such an evaluation is often required.

In order to realize such a unified examination on a cross-data basis, other techniques belonging to the field of data integration need to be taken into consideration (cf. Fig. 1). Data federation, which is studied within the field of Enterprise Information Integration (EII), might serve as one possible solution to enable a unified examination. With the help of EII, data from different data sources can be unified in one single view [BH08]. This single view is used to query for data based on a virtual, unified data schema. The query itself is processed by the EII system and divided in

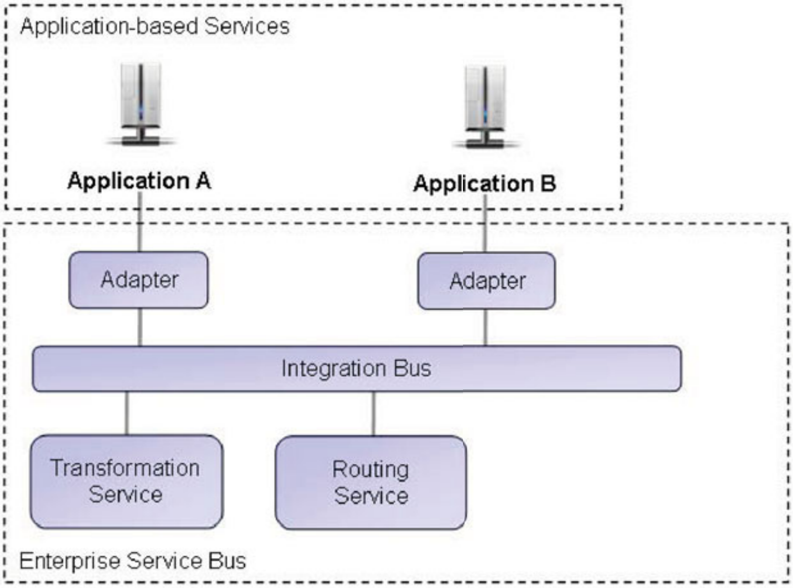

Fig. 2 Schematic structure of an Enterprise Service Bus

several queries fired against the underlying data sources. Because of the fact that most EII do not support advanced data consolidation techniques, the implementation will only be successful if the data of the different data sources can be unified, the data quality is sufficient and if access to the data is granted (e.g. via standard query interfaces).

If a virtual view is not applicable, techniques belonging to the field of data consolidation need to be utilized. Data consolidation comprises the integration of differing data into a common, unified data structure. Extract Transform Load (ETL) can be seen as one example for data consolidation, which is often used in the field of data warehousing [VSS02]. ETL starts with the extraction of data from one or several – mostly operational – data sources. The extracted data is than transformed (e.g. joined, modified, aggregated) and the data model is adapted to a final schema (often a so called star schema). During the last phase the data is than loaded into a target database (in general a data warehouse).

The presented techniques of data integration have in common that – independent of the technique the heterogeneity of data has to be overcome. In literature, different kinds of heterogeneity are distinguished [KS91, GMS97, LN07]. In this paper, the well-established kinds of heterogeneity listed in [LN07] are considered:

- Technical heterogeneity
- Syntactic heterogeneity
- Data model heterogeneity
- Structural or schema heterogeneity
- Semantic heterogeneity.

The problems occurring with each type of heterogeneity concerning data integration are manysided. The problem of technical heterogeneity, addressing the issue of accessing the data, can be handled for example with the help of modern message-oriented middleware techniques [Mye02]. Syntactic heterogeneity, which arises as a result of the representation of data (e.g. number formats, character encoding), can be overcome using common standards and conversion routines. The handling of data model heterogeneity is more complex. This kind of heterogeneity is given, if the data is represented by different data models (e.g. relation (RDBMS), hierarchical (XML) or structured (CSV)). Modern data integration solutions provide readers and writers to access data from popular data models and besides that, other data models can be implemented and supported through interfaces. The most complex kinds of heterogeneity are the structural and the semantic heterogeneity. Structural heterogeneity addresses the problem of representing data in one data model in different ways. One example is the usage of element attributes versus nested elements in a XML document. Semantic heterogeneity comprises differences in meaning, interpretation and type of usage of schema elements or data. Schema and ontology matching as well as mapping methods can be used to find alignments between data schemas and to process these alignments in a further step. Thereby, an alignment is a set of correspondences between entities of the schemas that have to be matched. In the past years, several matching and mapping algorithms have been published [ES07]. However, the focus of these methods is often a database schema, a XML schema or an ontology. Besides, the published methods do not regard the domain specific knowledge to determine the alignments [GSY06].

3 Use Case

Within this paper, the manufacture of a line-pipe will be stressed as example use case. During the manufacture several simulations via tools that are specialized for these techniques are used. The goal is the simulation of the whole production process, whereby the results of each specialized tool will be considered across the whole simulated production process. The production process which will be used to exemplify the example use case is illustrated in Fig. 3.

The use case starts with a simulation of the annealing, the hot rolling as well as the controlled cooling of the components via CASTS, an application developed by Access. The next step consists in representing the cutting and the casting with the help of Abaqus (Dassault Systems), whereas the welding and the expanding of the line-pipe will be simulated via SimWeld, a tool which was developed by the ISF (RWTH Aachen University), and via SysWeld, a software product contrived by the ESI-Group [RM07]. Furthermore, the simulation of modifications in the microstructure of the assembly will be realized by making use of Micress [LNS] and Homat [Las02] which were both developed by Access. All in all, the use case contains six different kinds of simulations, each based on different formats and models. Thereby, the required integration solution has to take different requirements into ac-

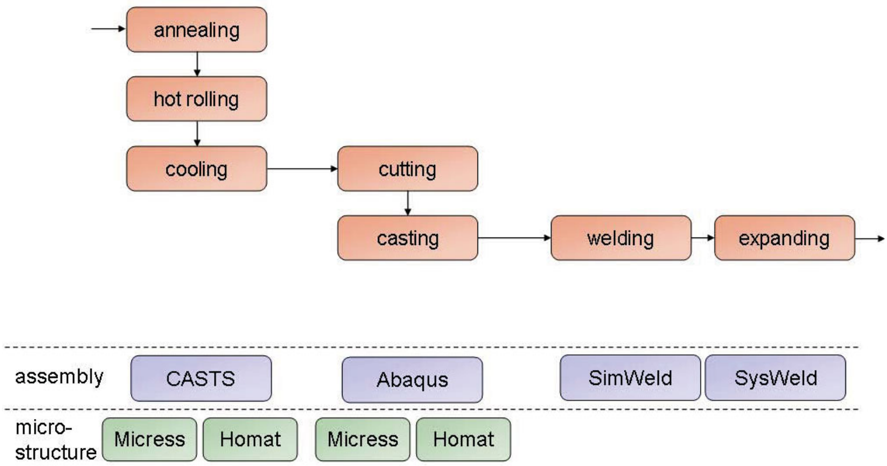

Fig. 3 Production process of a line-pipe

count [Sch10]. Two requirements, which turned out to be central with reference to the framework presented in this paper, are on the one side, the possibility of data propagation, focussing the semantic data exchange between the applications, and, on the other side, the necessity of a process-oriented data consolidation (cf. Fig. 1). Both of them are used to facilitate a subsequent visualization and analysis of data collected within the process. Another important requirement which has to be fulfilled is the easy adaption of the whole simulation (i.e. the simulation of the production process) concerning changes of the process (e.g. adding or replacing simulation tools, optimizing the process itself).

4 Architecture of the Framework

4.1 System Architecture

The framework's architecture is based on the requirements described in Sect. 3. The architecture is depicted in Fig. 4. As illustrated, the framework follows the architecture concept of ESB, whereby the possibility of data consolidation was realized by implementing a central data store [SGH08], the database server.

In order to realize a communication (e.g. concerning the exchange of files and overcome the technical heterogeneity) between the integration server and the different simulation tools (i.e. applications) a middleware is used that encapsulates the functionality of routing services which are typical of those used in ESB concepts[1].

[1] Within the use case mentioned in Sect. 3 the application-oriented middleware Condor [CBKB08] is used.

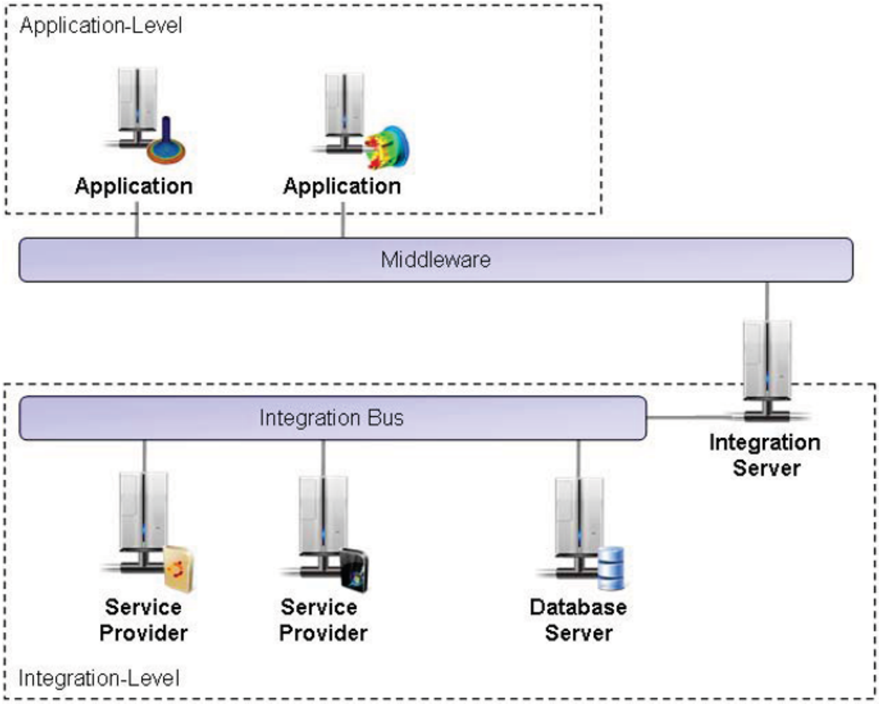

Fig. 4 System-architecture of the framework

Hence, routing services are not considered in this framework, as the integration of a standard middleware is straight forward. The framework is employed with the intention of realizing an integration level, at which service providers, which are directly linked to the integration bus, offer different services. With the help of these services, data can be integrated, extracted and transformed. As the connection is realized via the Java RMI Technology, it is not bound to the operating system in use. The employment of an integration server as well as of a database server marks an important difference between the architecture described in this section and the ESB architecture concept. The integration server receives all data transferred by the middleware, analyses it and, subsequently, makes it available for each of the service providers via the integration bus. In turn, the service providers tap the required data in order to process it. After a step of processing is finished, the integration server checks the consistency of the data with the aim of determining the next step.

Consequently, with regards to the processes of data integration and data extraction, the integration server undertakes the task of a central supervisory authority. A database server is used additionally as a central data store, which is also linked to the integration bus. The service provider and also the integration server have access to the database server, whereby data consolidation and, as a result, analyses of data collected during the process are possible.

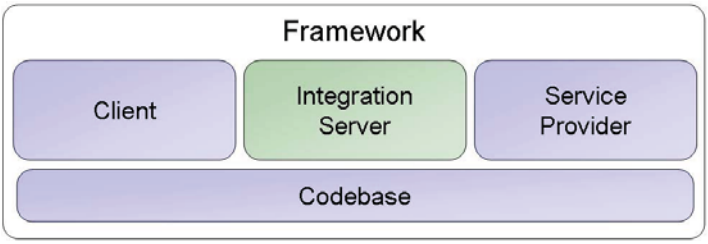

Fig. 5 Main components of the framework

4.2 Software Architecture

The framework comprises three main components:

- Middleware Communication
- Integration Server
- Service Provider

In order to guarantee a connection between those components, a codebase component is needed, in which a cross-component functionality is encapsulated. The main components are illustrated in Fig. 5. In the following, they will be described in detail.

4.2.1 Middleware Communication

The Middleware Communication component supports the realisation of communication processes between the middle-ware and the integration server. It contains adaptors, which facilitate the transmission of demands to the integration server by making use of different communication protocols, such as TCP/IP, RMI or SOAP [KBM08]. As far as a concrete use case is concerned, which is not covered by technologies that were already integrated, the component is modular expandable, which enables the implementation of additional separate adaptors (cf. Sect. 5).

4.2.2 Integration Server

The component called "Integration Server" comprises the implementation of a management component, which functions as a service provider and a central control unit for integration processes. The services provided by this component involve the integration, the extraction and the transformation of data. For each of these services, a service process is stored within the integration server, which is started and processed as soon as a client directs a question to the integration server concerning the corresponding service. A service process describes which services need to be

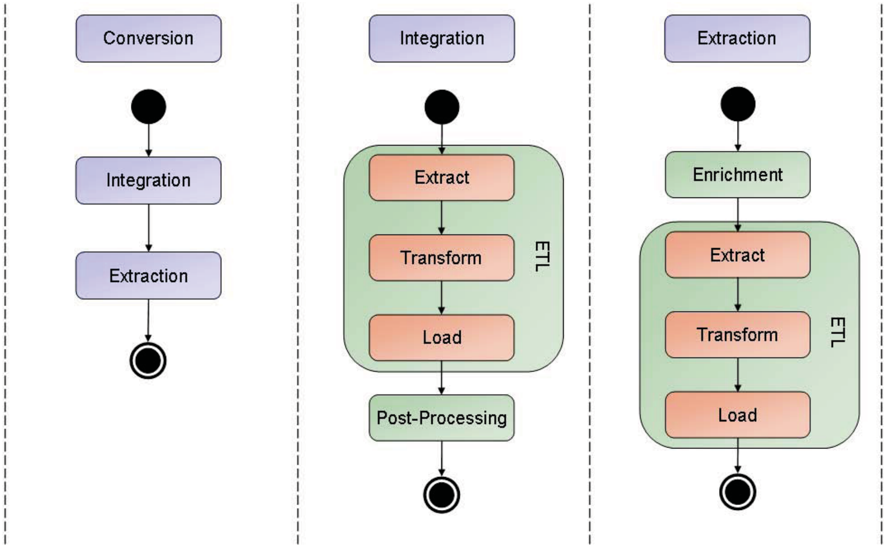

Fig. 6 Service Processes of the framework

handled with the purpose of providing the functionality requested by the client. The service processes realized within the framework are illustrated in Fig. 6.

The conversion process is defined by an integration process and an extraction process which are both based upon extended ETL process. Within the integration process, a post-processing of integrated data is succeeded, whereas the extraction process makes use of a data enrichment that is carried out prior to the actual ETL process. Furthermore, the steps which are marked green in Fig. 6 are functionalities that are made available by the service provider within the integration level.

Thereby, the integration server is used as a mediator with the help of which data is exchanged to those service providers that feature the postulated functionality and capacity. As a consequence, the algorithms, which are important for the process of data integration and which are depending on the use case in question, are encapsulated within the specified service providers. Additionally, the integration server realizes a process-related integration of data. Thereby, the integration server controls the assignment of data to the process step and transmits the context of the process in question to the service providers. The underlying entity-relationship model is depicted in Fig. 7.

Within this model, a process is marked by a name (attribute identifier), whereas each process step has an arbitrary name at its disposal (attribute identifier).

The course of the process is indicated by storing the successors of each process step, which are not restricted to a fixed number. In this way, complex processes – such as the provision of simulation data at the micro level (microstructure) as well as at the macro level (assembly) – can be taken into account.

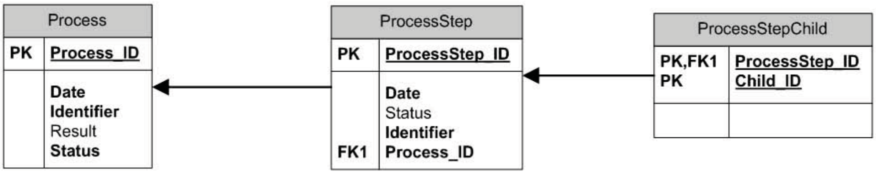

Fig. 7 ER-model for process dependent data integration

4.2.3 Service Provider

This component provides the fundamental functionality for service providers within the framework, whereby the implementation of a concrete service provider depends on the particular use case. For instance, the integration of FE data on the one hand and the integration of data of molecular structures on the other hand are based upon different data schemas, even though these processes of integration consist in the same physical object and deal with comparable physical entities.

The framework offers interfaces to common ETL tools as, for example, the Pentaho Data Integrator (PDI) [Lav06]. Thus, the integration and extraction of data, and therefore the overcoming of the syntactical and data model heterogeneity, can be created on the basis of these tools, which are already established in the domain of ETL. Furthermore, additional tools or frameworks can also be used in order to realize the processes of integration and extraction in the case that this way of proceeding is convenient and necessary within a concrete use case (cf. Sect. 5).

Apart from services which provide an ETL process, the framework supports additional services in order to post-process and enrich data. For instance, the post-processing service allows the implementation of plausibility criteria, which need to be fulfilled by the integrated data without reference to their original source. During the process of enrichment, data transformations are carried out with the purpose of editing data stored within the central data store in such a way that the data is able to meet the requirements demanded with regard to the extraction process. Therefore an adaptive data integration process [MSH09] is implemented in the framework. In the following section, the idea and the implementation of the adaptive data integration are described.

5 Adaptive Data Integration

5.1 Concept

The main goal of the adaptive data integration is to overcome the problems of structural and semantic heterogeneity considering domain specific knowledge. The adap-

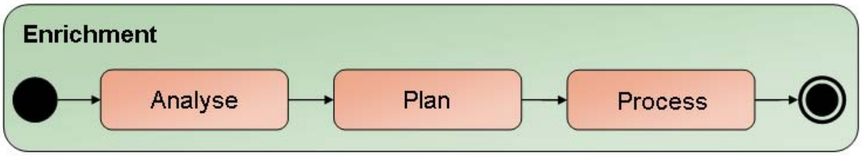

Fig. 8 Enrichment process

tive data integration is part of the enrichment process step in the extended ETL process being used during the extraction of data. The goal of the extraction process is to generate data in a given data format, regarding the data model and structure, as well as the semantics, of this format. Therefore, the implemented enrichment enables the discovery and exploitation of domain specific knowledge. The concept is based upon ontologies and planning algorithms from artificial intelligence. According to [Gru93] an ontology is an *explicit specification of a conceptualization*. In this paper, the stricter definition given in [SBF98] is used, in which an ontology is described as a *formal, explicit specification of a shared conceptualization*. The underlying enrichment process is depicted in Fig. 8.

First, the existing data is analysed. The goal of the analysis is the determination of so called features that are fulfilled by the data. A feature is domain specific and expresses a structural or semantic property that is satisfied by the data. Besides the analysis step determines features that have to be fulfilled by the data to satisfy the requirements of the specific output format of the extraction process. Following the analysis the planning algorithms are used to find a data translation that transforms and enriches the data, so that the enriched data fulfils the features needed by the output format. After the planning is finished, the found data translation is processed. The data transformation algorithms used for the data transformation are realized as a service. The information about the existing transformations and features is stored in an ontology. The basic structure of this ontology is described in the following section.

5.2 Ontology

The information used by the enrichment process is subdivided among a framework ontology and a domain ontology. The domain ontology holds information about the concrete transformations, features and applications used in the context of a specific domain. Besides, information about the domain specific data schema is stored. An extract of the domain ontology used to implement the use case is described in Sect. 6. There are many languages for defining ontologies [SS09]. The used ontologies are expressed in OWL, which is the ontology language recommended by the W3C.

The domain ontology has to specialise the concepts of the framework ontology in order to specify the conceptualization of the domain. Hence, the framework on-

Fig. 9 Ontology annotations

tology is a specification of the concepts used in the framework to enable the enrichment process. These main concepts are *data*, *feature*, *application* and *transformation*, which are introduced shortly.

The concept *data* is the generalization of all data concepts used in the domain. More precisely each concept in the domain ontology used to describe the data schema of the domain has to be a specialization of the concept *data*. The mapping between data concepts and the data schema of the domain is realised by using a predefined set of annotations. Because of the single mapping between a well-known ontology and a well-known database schema, automatic schema matching algorithms are not used. Instead this approach follows the concept of annotation-based programming. Figure 9 gives an overview of the main annotations.

To define domain specific features, the concept *feature* is used. A specialization of the concept *feature* is a listing of the requirements that have to be satisfied by a set of data. If these requirements are satisfied, the feature is fulfilled by the given data.

For each definition of applications and their requirements, instances of the concept *application* have to be expressed in the domain ontology. Besides the require-

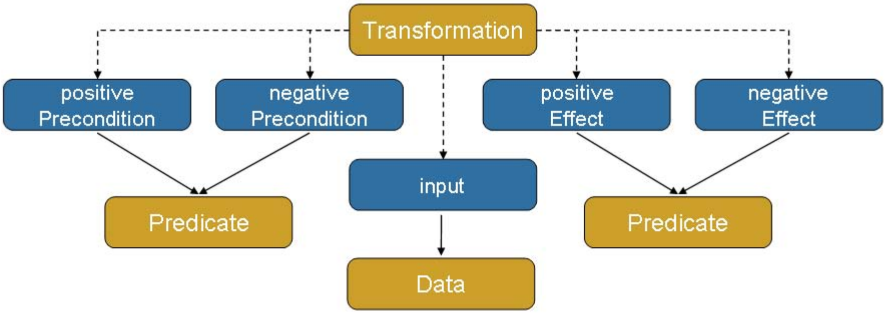

Fig. 10 Fragment of framework ontology – transformation concept

ments that are expressed using features, an instance of the concept *application* can have additional object properties to express domain specific information of an application. Similar to an application, a transformation has requirements that have to be satisfied. Otherwise, the transformation cannot be used. Therefore, each instance of the concept *transformation* has to outline the requirements by defining instances of *feature* concepts. In addition, a transformation changes the features of the data. This is realised by expressing the effects of the transformation in the ontology. The concept *transformation* and its main relations are depicted in Fig. 10. The colour code of the figure is identical to the colour code used in the ontology editor Protégé [KFNM04]. The used graphical representation of an ontology is taken from [ES07].

The input is set by an instance of the concept *data*, whereby the requirements are expressed by instances of either *positivePrecondition* or *negativePrecondition*. These object properties realize relations between the concrete *transformation* and feature instances. The framework ontology provides a set of logical connectives and quantifiers to express complex requirements like *feature1* **or** *feature2*. Similarly, the effects of the transformation are expressed.

5.3 Components

The concept of the adaptive data integration is realized by three subcomponents of the data management component. Each component implements one of the previously (cf. Fig. 8) described steps of the enrichment process (cf. Fig. 11).

The Data Analyser loads the ontology and establishes a connection to the data storage. By using the domain ontology, the features of the domain are determined. This is done by querying all defined specializations of the concept feature. Therefore, the OWL API [HB09] and the reasoner Pellet [SPG+07] are used. The fulfilment of a feature is checked by querying the data storage. The queries are generated by using the annotation based mapping. At the moment, the Data Analyser only supports relational databases as central data storage and SQL as a query language.

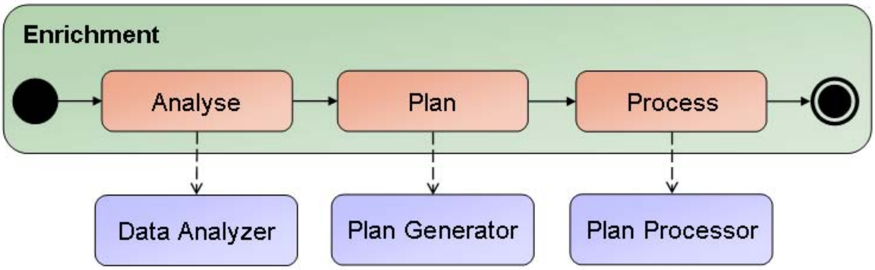

Fig. 11 Implementation of the enrichment process

The result of the query is analysed according to the feature definition. The use of database technology instead of reasoning was necessary because of the huge amount of data produced in the domain of material processing. For example, the classification of the geometry feature *plain* using reasoning without database support takes 26 minutes analysing a geometry with 2000 nodes. On the contrary, the reasoning using database queries takes less than one second.

The fulfilled features define the initial state of the data. In addition, the goal state is determined by the Data Analyser using reasoning. This means that the current context (required output format and domain specific parameters) is used to query the required features by using the information stored in the domain ontology.

Hence, the result of the Data Analyser consists of the initial and the goal state. This information is passed to the Plan Generator to determine the needed data translation. Therefore, the Plan Generator queries the existing data transformations from the domain ontology and generates a problem description using the Planning Domain Definition Language (PDDL) [FL03]. By using a planner the Plan Generator tries to solve the given planning problem. The planner is used to determine a sequence of, so called actions that lead from the initial state to a goal state. The framework supports different planning algorithms like forward, backward and heuristic search, STRIPS algorithm or Planning Graphs [GNT04, HN01]. If the planner succeeds a plan is generated that contains the transformations and their ordering to transform the data, so that the required features are fulfilled by the data after having processed the plan. Finally, the processing of the plan is realized by the Plan Processor. An example of the enrichment process will be given in the following section.

6 Application of the Framework

Within the domain of the use case described in Sect. 3 and the requirements resulting from the examination of four additional use cases in the domain of FE-simulations, an integration platform has been implemented in parallel to the implementation of the framework. The integrated applications are simulations based upon the finite-element-method. In order to implement the integration platform a domain specific

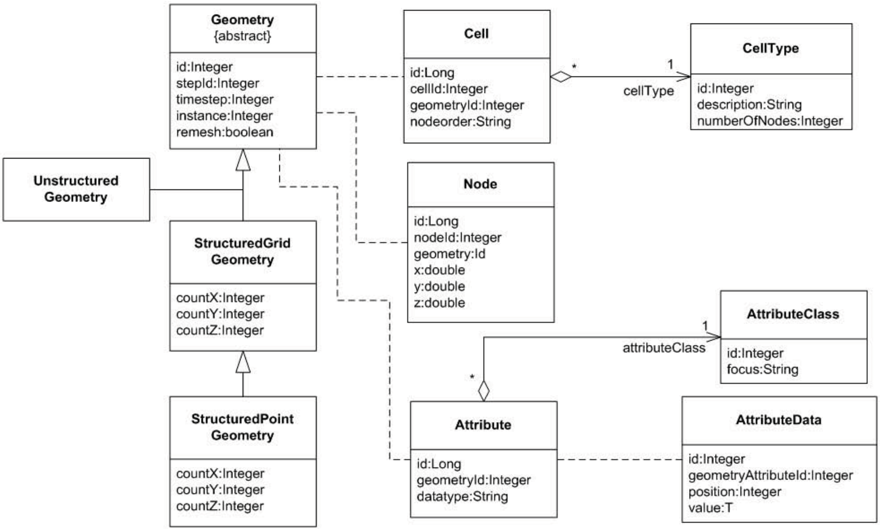

Fig. 12 Extract of the data schema used in the domain of FE-simulations

data schema, adaptors for integration and extraction, the transformation library and the domain ontology have been provided. In the following, some selected examples will be presented.

Data schema: The domain specific data schema has been determined by analysing the different input and output formats of the simulations used in the use case. Figure 12 depicts an extract of the generated data schema. The schema is drafted using the UML notation.

Within this data schema, the geometry of the assembly is the central entity. It consists of nodes, cells and attributes. The latter ones exhibit attribute values, which are assigned to individual cells or nodes depending on the class of attributes available in the whole geometry. The integration services, which were specified within the use case, read in the geometrical data provided by the simulation, transform it into the central data model and upload the results into the database. In contrast, the extraction services proceed as follows: The geometrical data is read out from the central database and transformed into the required format. Finally, the data is uploaded into the destination file or into the target database. Because of the prior enrichment, all of the structural and semantic data transformations have been performed. Hence, most of the data transformations formerly performed by the adaptors are omitted.

Adaptors: Most of the adaptors have been implemented using the PDI. If more complex data have been given, or binary formats that can only be read by programming interfaces of the manufacturer, either the PDI functionality have been extended using the provided plug-in architecture or the needed functionality has been implemented using Java or C++. For example, the simulation results generated within the simulation tool CASTS are stored in the Visualization Toolkits (VTK) format [SML04].

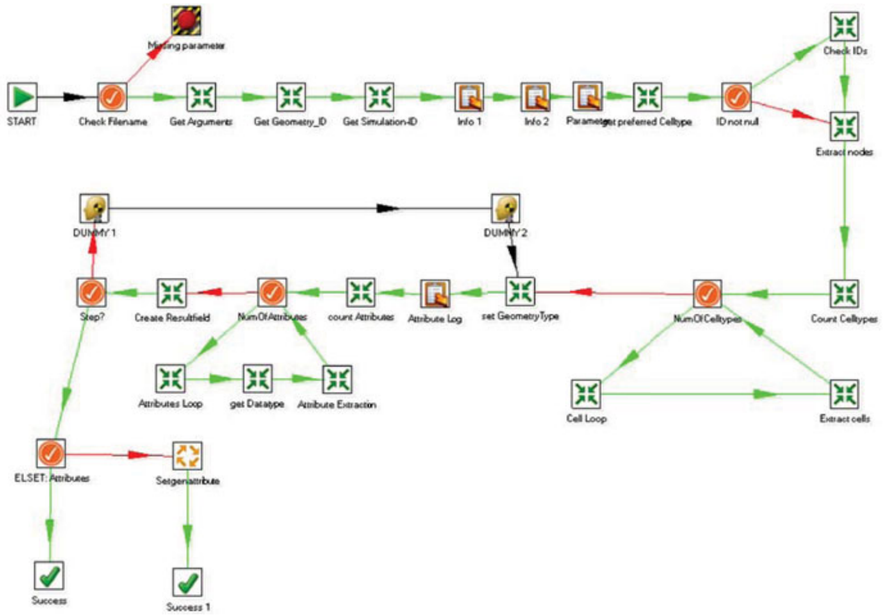

Fig. 13 Abaqus extraction as PDI transformation

Hence, an integration service was implemented, which is based on the programming interface provided by the developers of VTK using the provided functionality of the framework. Furthermore, an extraction service was developed with regard to the Abaqus input format, whereby, in this case, the aforementioned ETL tool PDI was used. In Fig. 13, an excerpt of the implemented PDI job is illustrated.

Transformation library: In order to realize the data integration, different sorts of data transformations for FE data were implemented into the application, for example the conversion of attribute units, the deduction of attributes from those ones that are already available, the relocating of the component's geometry within space, the modification of cell types within a geometry (e.g. from a hexahedron to a tetrahedron) or the reenumeration of nodes and cells.

Domain Ontology: In order to enable the adaptive data integration, the domain specific information has been expressed in the domain ontology. As described above, the domain ontology uses the concept of the framework ontology to express the data schema, the transformations, the applications and the features of the domain. Figure 14 sketches a fragment of the concept Geometry.

Because of the number of data and object properties, only a few are depicted. Most interesting is the data property *minNodeId*, which is a subproperty of *minimumValueProperty*. This kind of data property can be used to prompt the Data Analyser to use the SQL *MIN* function, whenever a classification requires such information. Analogous data properties for average and maximum exist within the framework ontology. The depicted object properties *node*, *cell* and *attribute* rep-

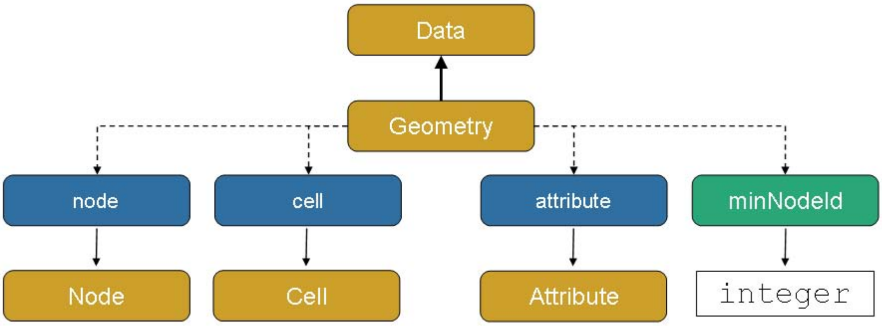

Fig. 14 Fragment of the concept Geometry

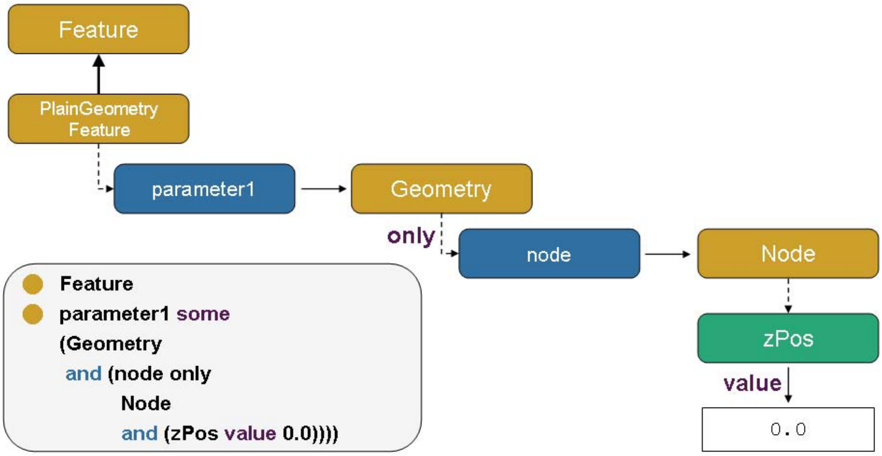

Fig. 15 Expression of the PlainGeometryFeature

resent the relation between the concept *Geometry* and the concept referred to by the object property. Using the previously described annotations the metadata of the relationship like primary and foreign keys are expressed.

The defined data schema is used to point out different data features of the domain. As described previously, a feature is a kind of classification of existing data. More precisely, if all conditions of a feature are fulfilled, the data belongs to the class represented by the feature. A simple feature is the already mentioned *PlainGeometryFeature* of the concept *Geometry*. It expresses that a geometry belongs to the class of *plain geometries* if all nodes of the geometry have the z-coordinate zero. The feature is expressed in the domain ontology as depicted in Fig. 15. The statement used in Protégé to express the feature is sketched as well.

Besides the data schema and the features the ontology contains information about the available transformations and the used applications. One example of a transfor-

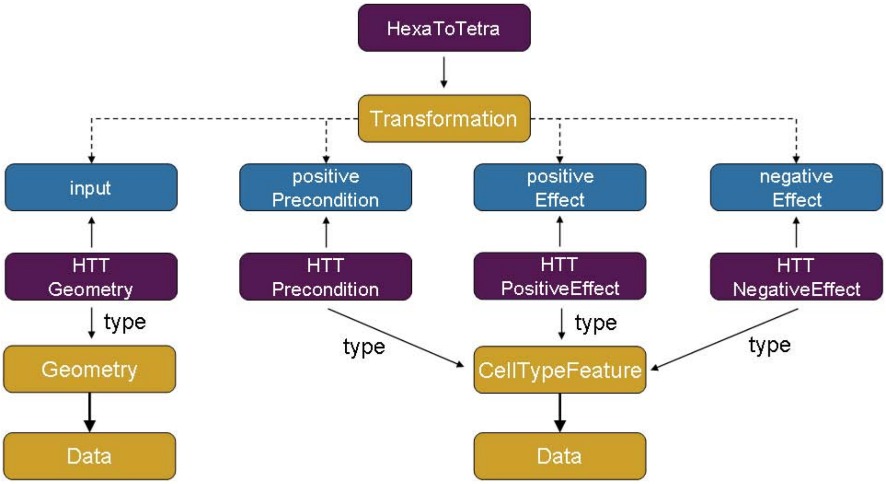

Fig. 16 Expression of the transformation HexaToTetra

mation is *HexaToTetra* that transforms a geometry based on hexahedrons into a geometry of tetrahedrons. The transformation searches all occurrences of hexahedrons within the geometry and splits them into tetrahedrons without creating new nodes. Hence, the precondition of the transformation is that at least one hexahedron exists in the geometry. The effect is that all hexahedrons are replaced by tetrahedrons. Preconditions and effects are expressed by using features. The expression of the transformation *HexaToTetra* in the domain ontology is illustrated in Fig. 16.

As described previously a concrete transformation is expressed by an instance of the concept *transformation*. According to Fig. 10 object properties have to be defined to express input, preconditions and effects. The instance *HTTGeometry* expresses that the transformation requires a geometry as an input. The preconditions and effects are depicted more detailed in Fig. 17.

The precondition is a concrete *CellTypeFeature* expressing that the geometry *HTTGeometry* consists of cells of the cell type hexahedron. Also, the effects are expressed using *CellTypeFeature*. The positive effect is that the resulting geometry contains cells of the type tetrahedron, whereas the negative effect is, that the concrete *CellTypeFeature* representing the hexahedron is forfeited.

Example: Concluding this section, a small example of the data provision of results generated by the simulation CASTS to the simulation Abaqus is presented. The example focuses on the structural changes of the data that are needed, in order to enable the usage of the data in Abaqus. Using the VTK data format, the indexing of nodes and cells begins with zero. Instead, Abaqus requires a sorted indexing starting with one. Additionally, in CASTS, vectors are decomposed into single components and stored as attribute values assigned to nodes, whereas in Abaqus, vectors need to be quoted entirely.

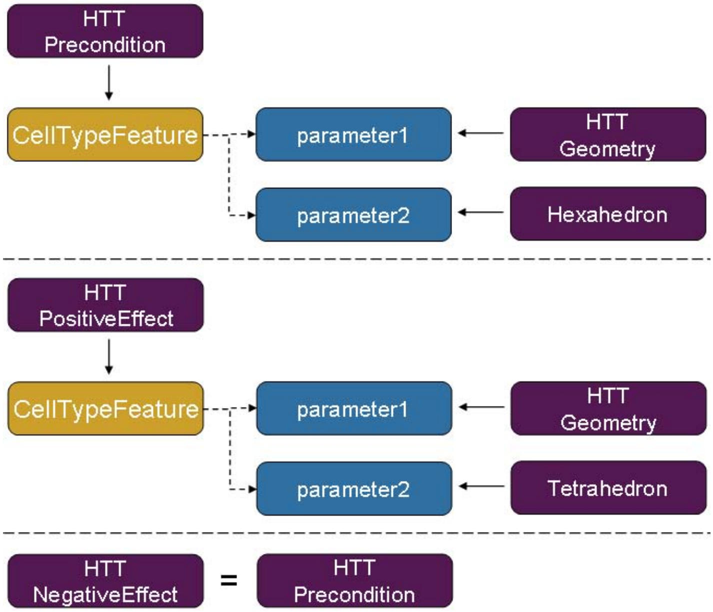

Fig. 17 Expression of preconditions and effects in HexaToTetra

Due to the data enrichment, the needed data transformations have been determined autonomously. In Fig. 18, a simplified illustration of the result of data translation from CASTS to Abaqus, which was specified for the use case described above, is presented.

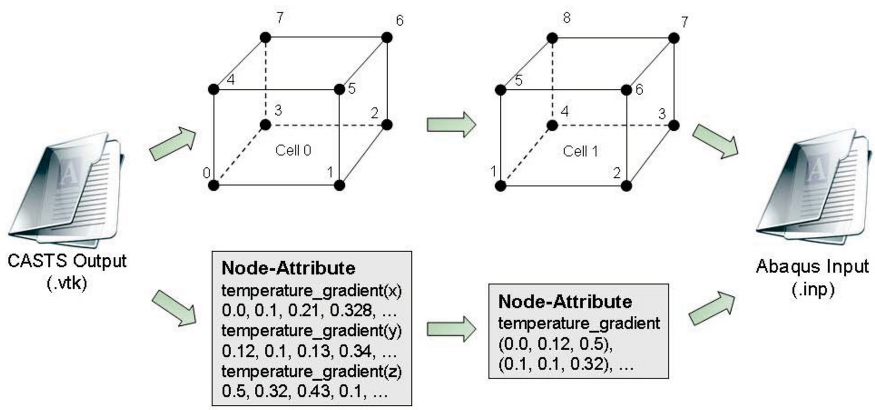

Fig. 18 Simplified illustration of the data translation

7 Conclusion

The development of the framework presented in this paper can be regarded as an important step in the establishment of integrated simulation processes using heterogeneous simulations. Both, data losses as well as manual, time-consuming data transmissions from one tool to another are excluded from this approach. The suggested framework facilitates the linking of simulation tools, which were – until now – developed independently and which are specialized for certain production processes or methods, too. Furthermore, the integration of data generated in the course of the simulation is realized in a unified and process-oriented way. Apart from the integration of further simulation tools into an application, which was already established, it is essential to extend the domain of simulations reflected upon with additional simulations covering the fields of machines and production. In this way, a holistic simulation of production processes is provided. Thereby, a major challenge consists in generating a central data model, which provides the possibility of illustrating data uniformly and in consideration of its significance in the overall context, which comprises the levels of process, machines as well as materials. Due to the methodology presented in this article, it is not necessary to adapt applications to the data model aforementioned. On the contrary, this step is realized via the integration application, which is to be developed on the basis of the framework. Because of the unified data view and the particular logging of data at the process level, the framework facilitates a comparison between the results of different simulation processes and those of simulation tools. Furthermore, conclusions can be drawn much easier from potential sources of error – a procedure which used to be characterized by an immense expenditure of time and costs. The realization of this procedure requires the identification of Performance Indicators, which are provided subsequently within the application. In this context, the development of essential data exploration techniques on the one side and of visualization techniques on the other side turns out to be a further challenge.

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IT-Infrastructure for an Integrated Visual Analysis of Distributed Heterogeneous Simulations

Tobias Meisen, Rudolf Reinhard, Thomas Beer, Daniel Schilberg, Sabina Jeschke

Abstract Computational simulations are used for the optimization of production processes in order to significantly reduce the need for costly experimental optimization approaches. Yet individual simulations can rarely describe more than a single production step. Hence, a set of simulations has to be used to simulate a contiguous representation of a complete production process. Besides, simulated results have to be analyzed by domain experts to gather insight from the performed computations. In this paper, an IT-infrastructure is proposed that aims at a rather non-intrusive way of interconnecting simulations and domain expert's knowledge to facilitate the collaborative setup, execution and analysis of distributed simulation chains.

Key words: IT-Infrastructure, Simulation Interconnection, Application Integration, Information Integration, Visualization

1 Introduction

Optimizations for an increasing efficiency in production are often achieved by making use of simulations. Because of high costs and time needs, it is hardly possible to realize such simulations by experiments of the complete production process. Therefore, the usual approach consists in the use of computational simulations, which minimizes the experimental effort [BB99, ZVG+95]. Unfortunately, these simulations mostly regard single aspects of the process and do not consider simulation results from previous steps in the simulated process. Interactions of effects

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on different scales are oversimplified or conditionally included in existing simulation approaches. Consequently, key factors, such as the material's history through the process, are neglected. To overcome these weaknesses of typical simulation approaches, an IT-infrastructure is presented including components that allow the interconnection of several simulation tools as well as an integrated analysis of the simulation results. This infrastructure has been successfully adopted to implement the AixViPMaP® (Aachen (Aix) Virtual Platform for Materials Processing) [SP09].

The paper is structured as follows: In the next section, the current state of the art will be outlined in order to provide a foundation for the following section, in which one of the implemented use cases is presented in detail. This brief introduction is followed by a section in which the components of the simulation platform are described. In the last section, a conclusion and outlook will be drawn from the insights generated in this paper.

2 State of the Art

In the field of simulations, the process development time using manually linked simulations incurs an overhead of 60 %, caused solely by the manual operation of the individual simulation components and conversion tools of a simulation chain [Lan03].

At the same time, integration problems belong to the most frequented topics with reference to finding answers to questions which are raised across application boundaries [HRO06]. The complexity of such integration problems arises by reason of the many topics that have to be regarded to provide a solution. Besides application interconnection on the technical level, the data has to be propagated and consolidated. Furthermore, user interfaces are required to model the underlying process and a unified visualization of the data for the purpose of analysis. The necessary visualization depends on the requirements of the user and therefore has to consider the user's background. In addition, the integration of data requires the understanding and thus the comprehension of domain experts. Because of those reasons, integration solutions are often specialized and highly adapted to the specific field of application. One example for such a solution is the Cyber-Infrastructure for Integrated Computational Material Engineering (ICME) [Hau10] concerning the interconnection of MATLAB applications. Other examples are solutions that require making adjustments on the source level of the application, like CHEOPS [SYvWM04]. Realizing a flexible solution, the technical, the data and the analysis level have to be taken into account.

The interconnection on the technical level has been researched intensively. Several solutions have been presented during the last years [Hen08, Nat03]. In particular the use of middleware technologies has been established to provide a solution to such kind of problems. Middleware solutions used in the field of simulation interconnecting often require linking of hardware resources, in addition to the associating of the simulations. This issue is addressed in the field of grid computing. Popular grid middleware agents include Globus [Fos06], g-lite, UNICORE and Condor [TTL08].

Concerning the data and information level, a conversion of the data syntax is not sufficient. Instead, the structure and the semantics of data have to be considered in the conversion process [Gag07]. For such processes, the usage of schema- and ontology-based integration methods [ES07, SES05] has been established as a solution. Thereby, research mainly focuses on data schemas based on the relational or XML data model. In this respect, knowledge bases containing background knowledge about the application domain are often used to facilitate the semantic integration of data [Gag07, GSY06]. There are various research projects in this field which have produced different solutions for schema- and ontology-based integration, like COMA++ [EM07] and FOAM [Ehr05]. Both systems feature algorithms analyzing the structure of the schema and do not regard the stored dataset. Hence, these systems are unable to identify different dataset semantics within one schema.

For the analysis of simulation results, first of all, an adequate visualization is required. Current simulation tools often comprise in-house solutions tailored to specific simulations. However, these are only suitable for visualizing the datasets generated by this particular simulation software. Hence, generic visualization solutions, such as ParaView [SD08] or OpenDX, are better suited to this purpose, mainly because of their wide support of meshes generated by finite-element-simulations. However, these applications are designed to extract and display visual features, such as isosurfaces, from individual datasets. Furthermore, they lack the means of interaction required to deal with all the simulation results of a simulated process chain in a common context.

3 Use Case

Within this paper, the production of a line-pipe will be stressed as an example use case. During the production process, several simulation tools are used that are specialized for the simulation of the needed production steps. The goal consists in the simulation of the whole process, whereby the results of each specialized tool will be considered across the whole simulated process. The production process which will be used to exemplify the use case is illustrated in Fig. 1.

The use case starts with a simulation of the annealing, the hot rolling as well as the controlled cooling of the components via CASTS, an application developed by Access e.V. The next step consists in representing the cutting and the casting with the aid of Abaqus (Dassault Systems), whereas the welding and the expanding of the line-pipe will be simulated via SimWeld, a tool which was developed by the Welding and Joining Institute (ISF) of RWTH Aachen University, and via SysWeld, a software product contrived by the ESI-Group [RM07]. Furthermore, the simulation of modifications in the microstructure of the assembly will be realized by making use of Micress [LNS98] and Homat [LA10], which were both developed by Access e.V. All in all, the use case contains six different kinds of simulations, each based on different data formats and models. Thereby, the required integration solution takes different requirements into account [MSH09]. Two requirements which

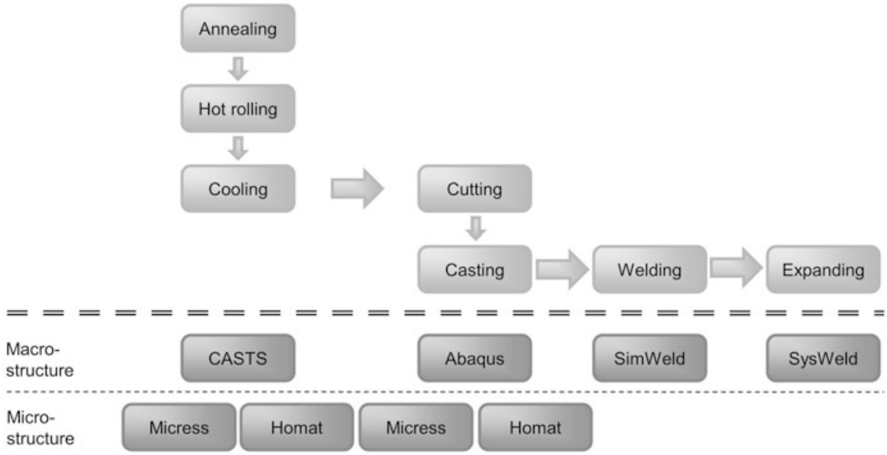

Fig. 1 Production process of a line-pipe and involved simulation tools

turned out to be central with reference to the presented IT-infrastructure are, on the one side, the possibility of data propagation focusing the semantic data exchange between the applications and, on the other side, the necessity of a process-oriented data consolidation. Both of them are used to facilitate the subsequent visualization and analysis of the collected data. In addition to this use case, the provided solution has been used to model four additional use cases that are consolidated in the domain of material processing.

4 Distributed Collaborative Simulation Platform

The overall architecture is based on a GRID approach. It utilizes the middleware Condor for centralized resource management and distribution of simulation tasks and data, thus using this middleware as a single point of contact for the platform users and to hide the complexity of the distributed system. Beside the simulation resources, an Information Integrator serves as a special resource in its role as translator between simulation resources. An Interactive Workflow Manager has been developed to define the simulation process and to select the involved simulation tools. Finally, the integrated analysis is realized by a visualization component.

4.1 Interactive Workflow Manager

The workflow manager is a web 2.0 application that enables the user to visually design simulation workflows. These workflows are automatically translated into de-

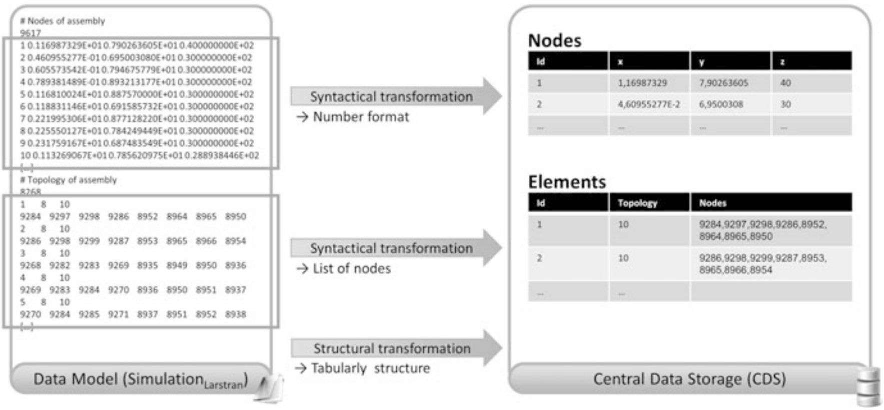

Fig. 2 Integration of data into the Central Data Storage (CDS)

scription files required by the Condor middleware and can then be executed from within the web interface. The resulting jobs are performed on the different distributed resources. Because the entire process is managed by a server-side component, there is no need to install any software on client machines in order to design and execute simulation chains.

4.2 Adaptive Information Integration

As already described, an integration solution is required to interconnect the different simulations on the syntactical, structural and semantic level. In the presented approach, the translation is realized by the Information Integrator service. The Integrator itself makes use of services to provide the needed functionality. Hence, the architecture of the Information Integrator is based as well upon a service-oriented approach. Thereby, a service bus [Cha04] realizes the communication between the different services. The main purpose of these services is to overcome the heterogeneity of the data. In literature, different kinds of heterogeneity are distinguished [KS91, LN08]. In this paper, the well-established kinds of heterogeneity listed in [LN08] are used. Thus the syntactical and the structural heterogeneity are overcome by making use of adapter services. In contrast to a common adapter-based approach, the adapter services do not need any domain-specific knowledge to fulfill their task. Their main purpose is to transfer the data stored in a file or database into a Central Data Storage (CDS) without considering the structure or the semantics of the data. The main concept is exemplarily sketched in Fig. 2.

Because of the huge data volumes that are examined in examined use cases, a relational database is used as CDS. For example, the data generated executing the presented use case exceeds more than ten gigabytes. The Information Integrator distinguishes two kinds of adapter services: Integration services are used to transfer

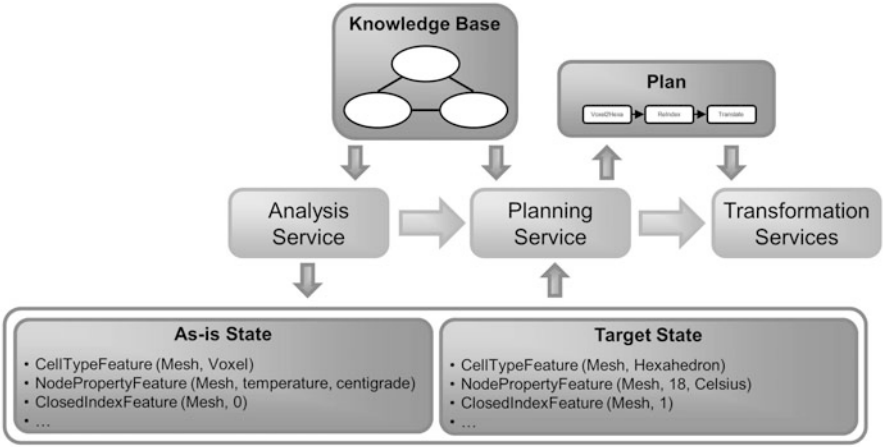

Fig. 3 Determination of a transformation process using services

data into the CDS, whereas extraction services are employed to transfer data from the CDS into a file or database.

After the data has been integrated into the CDS, it is further processed with analysis, planning and transformation services. Analysis services identify features that are fulfilled by the integrated process data (as-is state). In this manner, a feature is a domain-specific property or characteristic of data. Furthermore, the service analyzes which features have to be fulfilled so that the data can be extracted into a defined data format (target state). This information is forwarded to a planning service to determine a translation process that transforms the given set of features into the needed one. Finally, transformation services process the identified translation. The features as well as the transformations and their preconditions and effects, are described in a knowledge base. Figure 3 shows an example of the determination of a translation process by using analysis and planning services.

In the depicted example, the initial mesh consists of voxel elements and has a node property named temperature, which is measured in centigrade. In addition, the indexing of the nodes and elements is closed, which means there are no gaps in the numbering of the index, starting by zero. For extracting the data into the desired target format, the mesh has to fulfill a set of features, defined in the target state. These features determine that the mesh has to consist of hexahedrons and the temperature has to be presented by a property named 18. The indexing of nodes and elements has to be closed and started by one.

As result, the planning service determines a translation process, described by a plan, which translates the data into the desired target state. Following the example, the translation process contains three steps: VoxelToHexahedron, ReIndex and Translate. Each of these transformation steps is realized as a separated service within the Information Integrator (cf. Fig. 4).

Because of this new approach, the Information Integrator is robust against changes in the requirements of data formats according to the structure and the se-

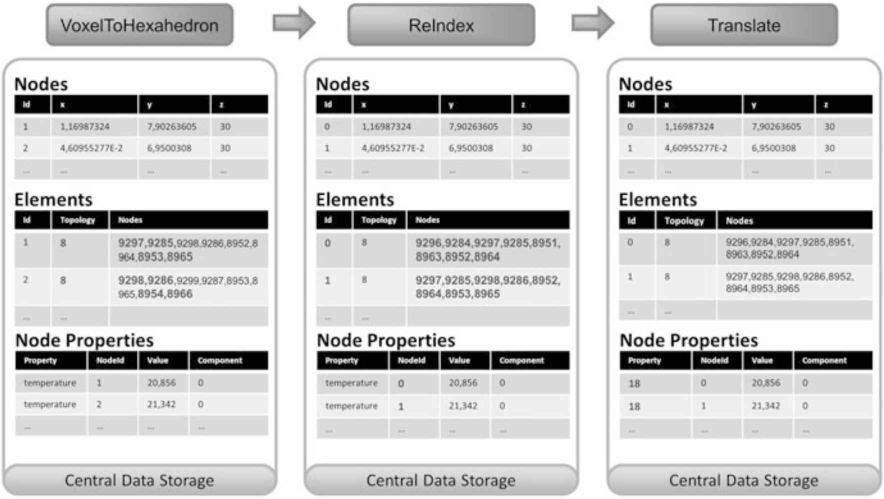

Fig. 4 Transformation process

mantics. Besides that, new data formats can easily be integrated by defining the integration and extraction service as well as the structural and semantic requirements. Transformation services are automatically included after they have been published in the knowledge base.

4.3 Virtual Integrated Simulation Analysis

The ultimate goal of performing simulations is a deeper understanding of the underlying processes and effects. Therefore, efficient means of data analysis are a mandatory component in the overall workflow. Hence, as the simulated phenomena can rarely be detected by generic computational methods, paradigms and tools, scientific visualizations serve to transform the vast amount of numerical results into a readily accessible visual representation. After the simulations have successfully delivered their results and thus formed a contiguous representation of material, visualizations of the different production steps have to be merged into a common context. This context involves not only multiple scales, but also different temporal and spatial resolutions as well as different data fields (e.g. temperatures at macro level, grain identifiers at micro level).

In a pre-processing step, the Information Integrator is used to translate all simulation data into a format suitable for visualizations. Because of the widespread distribution and wide acceptance, the PolyData-Format of the Visualization Toolkit software library [SML06] has been chosen. Moreover, a unified post-processing is executed. Because a visualization pipeline that filters semantically important information out of the heterogeneous simulation results from different domains is not yet fully automatable, it is realized as a manual preparation step. Within the post-processing, standard visualization objects, like object surfaces, cut-planes or isosurfaces, can be extracted for each dataset interactively. For performance reasons, just the surface meshes of the datasets are exported instead of driving the complete visualization pipeline in real-time during the analysis process. Besides performance issues, it is also a memory problem to keep full unstructured volumetric data for all simulations in-core at once. Hence it is necessary to use decimation algorithms to enable an interactive visual analysis process.

Decimation algorithms do have a long history and many different approaches are known [HD04]. The presented solution proposes the use of a pragmatic decimation method based on approximated centroidal Voronoi diagrams (ACVD) [VC04] that results in reasonably uniform mesh resolutions. This way, data values on flat surfaces that would be rejected by traditional geometric error metrics are preserved, while not generating too much computational load. For most datasets in the considered simulations chains, this approach delivers good quality. For the few other datasets, the automated decimation tool is configured to use a traditional decimation algorithm as provided by VTK. Which algorithm is used can either be set globally for a decimation session or on a per-dataset basis by adding a special tag to the metadata structure used for the visualization.

After the visualization data and the corresponding decimated version have been made available to the visualization front end, the integration into a common visualization context in a concerted manner enables the analysis and the discussion of phenomena along the whole process between domain experts. Thereby, multiple datasets are representing material and work piece states at different spatial scales, e.g. grain level (magnitude of μm) and work piece scale (magnitude of m), spatial locations, temporal scales (ranging from seconds to hours for sub-processes) and temporal locations. In order to avoid a lost-in-data situation and to help the analyst keep track of the spatiotemporal relations the datasets form in the simulated process chain, a hybrid 2D/3D user interface called the dataset sequencer is proposed. It focuses on interaction with the temporal setup of a visualization environment during the analysis process. With this component of the visualization system, a 2D "desktop" and 3D "immersive" means of interaction is offered, which both can be used on a wide range of target systems.

5 Conclusion

The presented IT-infrastructure has been successfully adopted to implement the AixViPMaP® that comprises more than ten simulation tools including commercial solutions like Abaqus. It contains general concepts which facilitate the interconnection of heterogeneous simulation resources at all technical layers from low level distributed scheduling and data transfer up to high-level visual design of simulation chains through a web interface. In the process, adaptive information integration assures data consistency at the syntactical, structural and semantic level. With these powerful tools at hand, the AixViPMaP® allows new ways of exploration, investigating simulation data at an inter-simulation tool level. Next, the underlying system will be extended by an analysis layer and an interactive user interface to trigger analysis via the visualization tool to provide a complete solution for simulation interconnection and integrated analysis – a so-called Virtual Production Intelligence solution.

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A Framework Enabling Data Integration for Virtual Production

Rudolf Reinhard, Tobias Meisen, Thomas Beer, Daniel Schilberg, Sabina Jeschke

Abstract Due to the increasing complexity of modern production processes, the use of tools providing their simulation is getting more and more common. The simulation of a production process in its entirety, depending on the level of detail, often requires the coupling of several, specialised simulation tools. The lack of uniform structures, syntax and semantics among the considered file formats, the special simulation context and the typical accumulation of huge data volumes, complicates the use of established enterprise application integration solutions. Thus, the need for a tailor-made framework for simulation integration purposes arises. The implementation of such a framework is requested to be easy adaptable, so that changes in virtual production circumstances causes only little efforts in the infrastructure, and at the same time taking care about domain specific purposes. This paper presents such a framework.

Key words: Information Integration, Interconnected Simulations, Integration Infrastructure

1 Introduction

Within the enterprising environment, the necessity to couple deviating applications being used within a company was recognized early. As a consequence, various concepts were developed that were subsumed under the collective term “Enterprise Application Integration” (EAI). In general, EAI focuses on the integration of business

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processes based on IT along the value chain of an enterprise without taking into account the platform, the architecture as well as the generation of the applications being used in these processes [SCT06]. Since a couple of years, enterprises that are established in the production-related environment tend to use techniques belonging to EAI. Examples of the use of such techniques are Business Intelligence (BI) or Enterprise Performance Management (EPM) systems. The fundament of those systems is based on integration methods to gain information about cross-application business processes [Pan05]. For example, a value-driven analysis, which is carried out along the value added chain, would be impossible without making use of such integration techniques. A fact seldom taken into account is the cross-application examination and analysis of other business processes like simulation processes [SP09]. Simulation as such is a well-established field in research and development. In fact, different simulations are available for specific tasks (e.g. simulations for casting, welding or cooling in material processing) as well as for whole processes (e.g. transformation or heat treatment processes). Nevertheless, those simulations have to be seen as isolated applications, which are, in most cases, specialized for a single purpose and which do neither have standardized interfaces nor standardized data formats. Therefore, different results received within a simulation can only be integrated into a simulation process if they are checked manually and adapted to the needs of following simulations – a step which is both time-consuming and fault-prone. In addition, concerning the simulation context, current EAI solutions cannot be used for the integration of data. On the one hand, the huge data volumes, which are characteristic of simulation processes, are not supported by current EAI solutions. On the other hand, the possibility of adapting the simulation process to changing conditions (e.g. the integration of a new simulation tool, the modification of a simulated object) is poorly supported. Furthermore, standards are needed in order to advance integration efforts within a simulation environment.

Because of these facts, a framework is needed, which provides the possibility of simulating a production process by making use of existing isolated applications. In this paper, such a framework and its application in a selected use case will be presented. It focuses on the integration of data that was generated during the applications' usage, whereas the applications' linkup technique, which can be handled with the help of modern middleware techniques [SCT02], will not be stressed. The framework has been developed within the project "Integrated Platform for Distributed Numerical Simulation", which is a part of the Cluster of Excellence "Integrative Production Technology for High-Wage Countries", located at the RWTH Aachen University and funded by the German Research Foundation (Deutsche Forschungsgemeinschaft – DFG).

The paper is structured as follows: In Sect. 2, the current state of technology will be outlined in order to provide a basis for Sect. 3, in which a use case of the framework presented in this paper will be described. Section 4 consists of a description of the architecture of the framework, which is completed in Sect. 5 by a specification of the adaptive data integration. Section 6 points out how the framework needs to be extended with regard to the presented use case. In Sect. 7, a conclusion and outlook will be drawn from the insights generated in this paper.

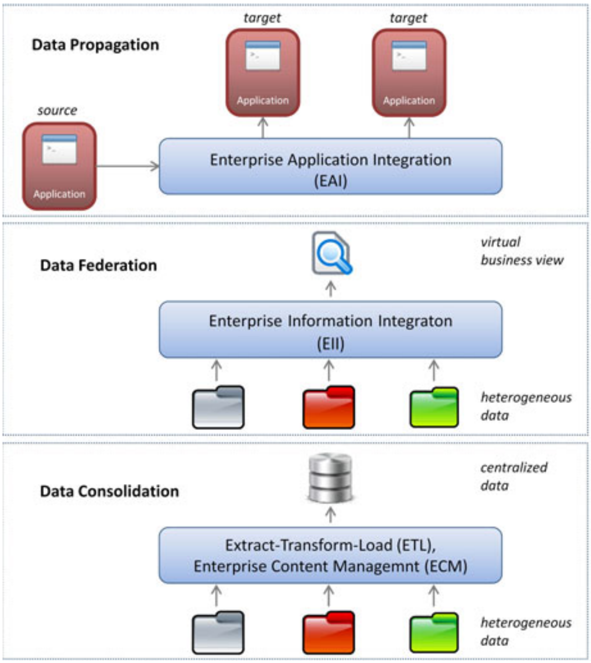

Fig. 1 Main areas of data integration [Whi05]

2 State of the Art

Since the eighties, but at least since the nineties, data integration as well as EAI belongs to the most frequented topics across application boundaries [AHO06]. Today, a multitude of data integration products can be found, which are used in different fields of application. In general, those products can be sub-divided into three sections [Whi05] (cf. Fig. 1):

- Data Propagation
- Data Federation
- Data Consolidation.

With regard to the operational section, Data Propagation is applied in order to make use of data on a cross-application basis, which is often realized via EAI. As already presented in [Whi05], EAI mainly focuses on small data volumes like messages and business transactions that are exchanged between different applications. In order to realize EAI, a contemporary architecture concept is used, which was developed in connection with service-based approaches [Cha04] and which will be emphasized within this contribution – the so called Enterprise Service Bus (ESB). The basic idea of ESB, which can be compared to the usage of Integration Brokers, comprises the provision of services within a system [Sch02]. Each service provides a technical or technological functionality with the help of which business processes are supported. All services are connected with each other via the Integration Bus. Transformation services provide general functions in order to transfer data from one format and model into another one. Against that, routing services are used to submit data to other services. Both transformation and routing services are used by adaptors in order to transfer data provided by the Service Bus into the format and the model of an application. Consequently, transformation services support the reuse of implemented data transformations. The advantage of a solution based on the ESB pattern is to be seen in the loose coupling of several services, whereas the missing physical data coupling can be regarded as a disadvantage [RD08]: If recorded data has to be evaluated or to be analyzed subsequently (e.g. with the help of data exploration techniques like OLAP or Data Mining), it will have to be read out and to be transformed once again. According to this fact, a historic or at least long-term oriented evaluation of data is unconvertible. In order to realize a unified examination on a cross-data basis, other sections belonging to the field of data integration need to be taken into consideration (cf. Fig. 1). Data Federation, which is examined within the field of Enterprise Information Integration (EII), might serve as one possible solution to enable a unified examination. With the help of EII, data, which is stored in different data sources, can be unified in one single view [Whi05, BH08]. This single view is employed by the user to query this virtual, unified data source. The query itself is processed by the EII system by interrogating the underlying, differing data sources. Because of the fact that most EII do not support advanced data consolidation techniques, the implementation will only be successful if the data of the different data sources can be unified and if access to this data is granted (e.g. via query interfaces). Otherwise, techniques belonging to the field of Data Consolidation, which comprises the integration of differing data into a common, unified data structure, need to be utilized. Extract-Transform-Load (ETL) – a current process with regard to data integration – can be seen as one example of data consolidation [PVS02]. ETL consists of the following aspects: The extraction of data from one or several – mostly operational – data sources, the transformation of the data format as well as of the data model into a final schema and, finally, the uploading of the final schema to the target data base. The presented sections of data integration have in common that, independent of the type of integration, the heterogeneity of data has to be overcome. In literature, different kinds of heterogeneity are distinguished [BH91, Goh97]. In this paper, the types of heterogeneity listed in [Les] are stressed:

- Technical heterogeneity
- Syntactic heterogeneity
- Data model heterogeneity
- Structural or schema heterogeneity
- Semantic heterogeneity.

The problem of technical heterogeneity, which addresses the problem of accessing data, can be handled with the help of modern middleware techniques [SCT02]. Syntactic heterogeneity, a problem arising as a result of the representation of data (e.g. number formats, character encoding), is solved by adapting the existing representation into the required one. The handling of data model heterogeneity is more complex, as this kind of heterogeneity can be traced back to data using different data models (e.g. relational database, XML data model, structured text file). Nevertheless, modern data integration solutions provide readers and writers to access data from popular data models like relational databases or XML. Besides that, the support of other data models can be implemented. The combination of both structural and semantic heterogeneity is the most complex form of heterogeneity. Structural heterogeneity addresses the problem of representing data in one data model in different ways, for instance the usage of element attributes versus nested elements in a XML document. Semantic heterogeneity comprises differences in meaning, interpretation and in the type of usage of schema elements or data. Schema and ontology matching as well as mapping methods can be used to find alignments between data schemas as well as to process these alignments. Thereby, an alignment is a set of correspondences between entities of schemas that have to be matched. In the past years, several matching and mapping algorithms have been published [ES]. However, these methods often focus database schemas, XML schemas and ontologies without taking into account the background domain specific information [FGY06]. This paper will not take a closer look at the topic of ontologies.

A further approach to handle the heterogeneity of data consists in the a priori restriction of used tools within the considered simulated production process (cf. Sect. 3). The calling for a kind of heterogeneity that is predictable via a before restrictered set of simulation tools implies a low flexibility the corresponding architecture provides. The user may not employ the specialization of a single tool for a special purpose and is thus forced to disclaim qualified results in a special case.

3 Use Case

During procedures like the manufacture of a linepipe, different production processes are put to use. Within the use case, these processes are simulated via tools that are specialized for these techniques. The use case starts with a simulation of the annealing, the hot rolling as well as the controlled cooling of the components via CASTs, an application developed by Access. Within a further step, the cutting and the casting will be represented with the help of Abaqus (Dassault Systems), whereas the welding and the expanding of the linepipe will be simulated via SimWeld, a tool which was developed by the ISF (RWTH Aachen University), and via SysWeld, a software product contrived by the ESI-Group [UDER07]. Furthermore, the simulation of modifications in the microstructure of the assembly will be realized by making use of Micress [GL] and Homat [Las02], which were both developed by Access. All in all, the use case contains six different kinds of simulations, each of them based on different formats and models. Apart from that, the project "Integrated Platform for Distributed Numerical Simulation" comprises four additional use cases, on which the requirements directed to the framework are based. Nevertheless, these use cases will not be stressed in the following. The requirements

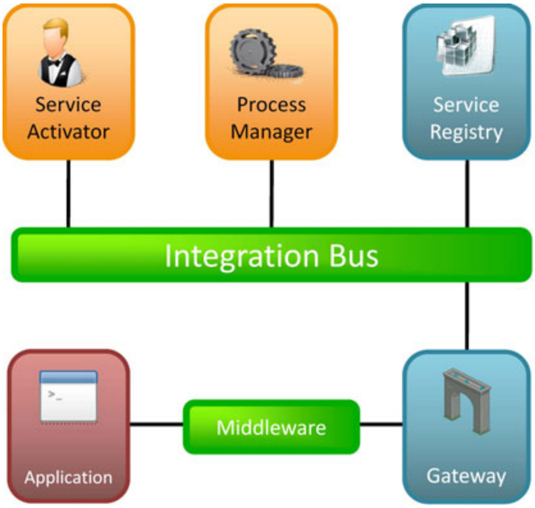

Fig. 2 The system architecture of the framework

aforementioned were already examined and described in [SM09] and, additionally, completed in [Sch]. Two requirements, which turned out to be central with reference to the framework presented in this paper, are the possibility of Data Propagation and the necessity of a process-oriented Data Consolidation (cf. Fig. 1). Both of them are used to facilitate a subsequent visualization and analysis of data collected within the process. Another important demand concerns the implementation of the following aspects without having to adapt the application significantly: the illustration of new simulation processes as well as the integration of new simulation tools.

4 Architecture of the Framework

The framework's architecture is based on the requirements described in Sect. 3. The architecture is illustrated in Fig. 2. In order to realize a communication process between the integration server and the applications, a middleware is used that ncapsulates the functionality of routing services, which are typical of those ones used in ESB concepts (e.g. within the use case mentioned in Sect. 3, the application-oriented middleware Condor [DTL05, PCB08] is employed). Hence, routing services are not considered in this framework because the integration of standard middleware is straight forward. The framework is employed with the intention of realizing an integration level at which service providers, which are directly linked to the Integration Bus, make different services available. Due to the fact that the integration architecture needs to allow the easy substitution of one application by another one, the choice of a service-oriented architecture was inevitable. In the following, there will be a concise explanation of the architecture's components.

The Services considered in this architecture comprise the following tasks: integration, extraction (both of them act as translators), analysis, transformation and planning. The Integration Services care about the processing of data for the further use by a particular application. That's why the Service Integration interface needs an own specialised implementation for each integration purpose. The Analysis Service checks the data that has been just inserted into the database concerning their current structure and the requested structure for the next simulation tool within the simulated production process. It determines how the current data have to be processed for the next step. This is the task of the Analysis Service. To define the transformation steps needed to prepare the data, such that they can be processed by the next simulation tool within the simulated production process, the Analysis Service has to parse the message to know which processes are necessary to fulfill the requirements written into the message. Each implementation of the Transformation Service cares about exactly one special aspect in the existing data. This could be for example the indexing of nodes within a geometry. A necessary data model requirement for this purpose is the link between the node objects and "their" geometry object. There are applications starting the indexing for nodes with 0 and others with 1 as well as a random number determined during the creation of the geometry. By trying to interconnect two of those tools with each other the necessity is obvious to change the index of the existing data such that it can be understood by the next tool. Another simple example is the conversion of temperature of a work piece from °C to °F. In most cases it is not sufficient to make more than one step to modify output data of one application such that they can be processed by the next application. An important constraint is the order, in which these transformations have to be executed. Since the request exists to obtain a fully automated interconnection of applications, also the determining of the kind of transformations and their execution order. This is where Planning Services come into consideration. It determines the kind of Services needed to perform the required operations and how to they have interact, that is among other things their order.

After their preparation by the appropriate, transformation data get extracted by an Extraction Service. The Extraction Service cares about the extraction of data, which got recently processed by an application and is meant to get used by another one. The simulation results on the other hand are within a file with a particular format. In certain cases it might be necessary to modify the input data. This step is called Enrichment.

Since the communication between all components is message driven the question arises, which message is activating a specified service. The Process Manager answers this question. It controls the realisation of the current step by the appropriate service instance within a running integration or extraction process. It does not know which functionality can be provided by any service, neither about the data a service needs to run. Thus there is the need for an instance having exactly this knowledge. This instance is called Service Registry. It direct the information about available services, the functionality each one provides and which input data each one requires to run properly.

Since a service does not provide any capability to communicate over messages it needs a further instance to undertake this task. This instance is the Service Activator. Each Service has its own Service Activator, whereas a Service Activator might also handle several Services. The Service Activator listens to the Integration Bus with the intention to identify any messages containing queries, which could be executed by one of the Services it cares about. The message contains beside the query itself also information about the requirements on the service which has to process it. In the case there is a query matching the capability of one the Services entrusted to the Service Activator's care, it locks one of its services to process this message and marks it as "in work", so that there is no other service processing this query. The processing's result is getting packed into a further message by the Service Activator and put into the Integration Bus'queue.

Each process within a simulated production process is managed by an instance called Process Manager. It writes messages containing queries into the Integration Bus' Queue, such that processes can be executed by a service and cares about the process initiation and eradication. The Integration Bus consists in particular of a queue containing the different queries the Process Manager writes into. The messages get read by the at least one Service Activator. A Gateway always belongs to a single application, which does not possess any capability to communicate with other architecture components over the Message Bus. The Gateway provides access for the architecture components to the application it belongs to and vice versa [GH].

The described components, in particular the service oriented architecture allow to implement the concept of data integration in an adaptive way. This point is getting considered in the following section.

5 Adaptive Data Integration

The main goal of the adaptive data integration is to overcome the problems of structural and semantic heterogeneity. The adaptive data integration is part of the enrichment process step, which can be assigned to the extended ETL process being used during the extraction of data. The objective of the extraction process consists in the generation of data in a given data format, taking into account the data model and structure as well as the semantics of this format. Therefore, the implemented enrichment allows for the discovery and exploitation of background-specific information. The concept is based upon ontologies and planning algorithms that are usually applied in artificial intelligence. The underlying enrichment process is depicted in Fig. 3. In the first instance, the existing data is analyzed. The goal of the analysis is the determination of so-called features that are fulfilled by the data. A feature is domain-specific, which means that it is expressing a structural or semantic property of the domain. Besides, the analysis step determines features that have to be fulfilled by the data to satisfy the requirements of the specific output format of the extraction process. Subsequent to the analysis, planning algorithms are used to find a data translation that transforms and enriches data in a way that allows for the fulfillment

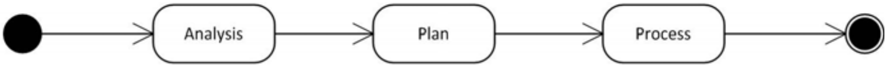

Fig. 3 Enrichment process

of features needed by the output format. After the planning is finished, the data translation, which can be found within this step, is processed. The domain-specific data transformation algorithms are stored in a transformation library following the ESB architectural concept, whereas the information about existing transformations and features is stored within an ontology. According to [Gru93], an ontology is an explicit specification of a conceptualization. In this paper, the ontology-driven data integration will not be focused due to the limited space, which will not suffice to describe it in a proper way.

6 Application of the Framework in the Use Case

Within the domain of the use case described in Sect. 3 and the requirements resulting from the examination of four additional use cases in the domain of FE-simulations, an application is implemented in parallel to the realisation of the framework. The regarded applications are simulations that use the finite-element-method [ZT]. With regard to the implementation of an application, which is based upon the framework, a domain specfic data schema, services for the integration and extraction process, the transformation library and the domain ontology have to be provided. In the following sections, some examples of the use case are presented.

Data schema: The domain-specific data schema has been determined by analyzing the different input and output formats of the simulations that were employed in the use case. It is depicted in Fig. 4. Within this data schema, the geometry of the assembly is the central entity. It consists of nodes, cells and attributes. The latter ones exhibit attribute values, which are assigned to individual cells or nodes depending on the class of attributes available in the whole geometry. The integration services, which were specified within the use case, read the geometrical data provided by the simulation, transform it into the central data model and upload the results into a database. In contrast, the extraction services proceed as follows: The geometrical data is read out from the database and is transformed into the required format. Finally, the data is uploaded into the destination file or into the target database. Because of the prior enrichment, all structural and semantic data transformations have been carried out. Hence, most of the data transformations formerly performed by the integration and extraction services are omitted.

Integration and extraction service: Most of these services have been implemented using the Pentaho Data Integrator (PDI) [in09]. In case that more complex data or binary formats, which can only be read by programming interfaces of the manufacturer, have been given, either the PDI functionality have been extended using the provided plug-in architecture or the needed functionality have been imple-

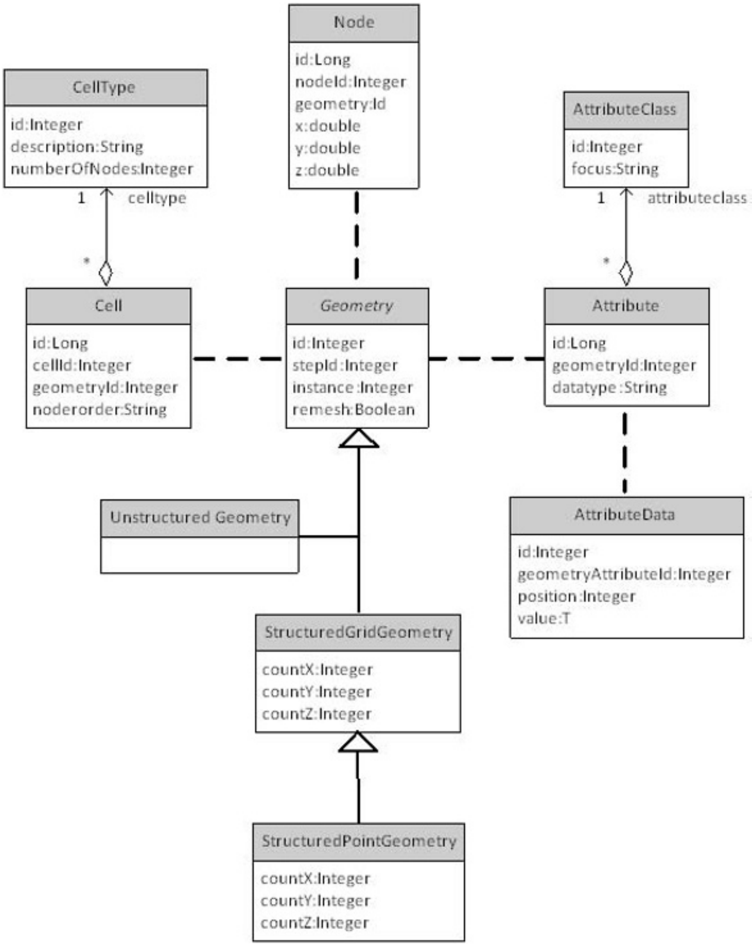

Fig. 4 Extract of the data schema used in the domain of FE-simulation

mented using Java or C++. For example, the simulation results generated within the simulation tool CASTS are stored in the Visualization Toolkits (VTK) format [WSL04]. Hence, an integration service was implemented, which is based on the programming interface supported by the developers of VTK using the provided functionality of the framework. Furthermore, an extraction service was developed with regard to the Abaqus input format, whereby, in this case, the aforementioned ETL tool PDI was used.

Transformation service: In order to realize the data integration, different sorts of data transformations for FE data were implemented as services, for example the conversion of attribute units, the deduction of attributes from those ones that are already available, the relocating of the component's geometry within space, the modification of cell types within a geometry (e.g. from a hexahedron to a tetrahedron) or the forementioned re-enumeration of nodes and cells. *Domain Ontology*: In order to enable the adaptive data integration, the domain specific information have been expressed in the domain ontology. As described the domain ontology uses the concept of the framework ontology to express the data schema, the transformations, the applications and the features of the domain.

Because of the number of data and object properties only a few are depicted. Most interesting is the data property minNodeId. This property is a sub-property of minimumValueProperty. This kind of data property can be used to prompt the Data Analyzer to use the SQL MIN function, whenever a classification requires such information. Analogous data properties for average and maximum exists within the framework ontology. The depicted object properties node, cell and attribute representing the relation between the concept Geometry and the concept referred by the object property. Using the previously described annotations the meta data of the relationship like primary and foreign keys are expressed. The defined data schema is used to express different data features of the domain. As described previously a feature is a kind of classification of existing data. More precisely, if all conditions of a feature are fulfilled, the data belongs to the class represented by the feature.

A simple feature is the *PlainGeometryFeature* of the concept Geometry. It expresses that a geometry belongs to the class of plain geometries if all nodes of the geometry have the z-coordinate zero. Also the statement used in Protégé to express the feature is sketched. Besides the data schema and features the ontology contains information about the available transformations and the used applications. One example of a transformation is HexaToTetra that transform a geometry based on hexahedrons into a geometry of tetrahedrons [TA03]. The transformation searches all occurrences of hexahedrons within the geometry and split them into tetrahedrons without creating new nodes. Hence, the precondition of the transformation is, that at least one hexahedron exists in the geometry. The effect is that no more hexahedron exists, but tetrahedrons instead. Preconditions and effects are expressed by using features.

As described previously a concrete transformation is expressed by an instance of the concept transformation. The instance *HTTGeometry* expresses that the transformation requires a geometry as input. The precondition is a concrete *CellTypeFeature* expressing that the geometry *HTTGeometry* has cells of the cell type hexahedron. Also, the effects are expressed using *CellTypeFeature*. The positive effect is, that the resulting geometry contains cells of the type tetrahedron, whereas the negative effect is, that the concrete CellTypeFeature representing the hexahedron is forfeited. Example: Concluding this section a small example of the data provision of results generated by the simulation CASTS to the simulation Abaqus is presented.

The example focusing the structural changes of the data needed to be done, to enable the usage of the data in Abaqus. Using the VTK data format the indexing of nodes and cells begins with zero. Instead Abaqus requires a sorted indexing starting with one. Additionally, in CASTS, vectors are decomposed into single components and stored as attribute values assigned to nodes, whereas in Abaqus, vectors need to be quoted entirely. Due to the data enrichment, the needed data transformations have been determined autonomously.

7 Conclusion

The development of the framework presented in this paper can be regarded as an important step in the establishment of digital production, as the framework allows a holistic, step-by-step simulation of a production process by making use of specialized tools. Both, data losses as well as manual, time-consuming data transmissions from one tool to another are excluded by this approach. The suggested framework facilitates the linking of simulation tools, which were, "until now", developed independently from each other and which are specialized for certain production processes or methods, too. Furthermore, the integration of data generated in the course of the simulation is realized in a unified and process-oriented way. Apart from the integration of further simulation tools into an application that was already established, it is essential to extend the domain of simulations reflected upon with additional simulations covering the fields of machines and production. In this way, a holistic simulation of production processes is provided. Thereby, a major challenge consists in generating a central data model, which supports the possibility of illustrating data uniformly and in consideration of its significance in the overall context, which comprises the levels of process, machines as well as materials. Due to the methodology presented in this article, it is not necessary to adapt applications to the data model aforementioned. On the contrary, this step is realized via the integration application, which is to be developed on the basis of the framework. Because of the unified data view and the particular logging of data at the process level, the framework facilitates a comparison between the results of different simulation processes and simulation tools. Furthermore, conclusions can be drawn much easier from potential sources of error – a procedure, which used to be characterized by an immense expenditure of time and costs. The realization of this procedure requires the identification of Performance Indicators, which are provided subsequently within the application. In this context, the development of essential data exploration techniques on the one side and of visualization techniques on the other side turns out to be a further challenge.

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A Framework Providing a Basis for Data Integration in Virtual Production

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Abstract In modern production the complexity of processes increases continuously. Therefore, the virtual planning of these processes simplifies their realisation extensively and decreases their implementation costs. The development of the framework presented in this article allows a holistic, step-by-step simulation of a production process by making use of specialized tools. Both, data losses as well as manual, time-consuming data transmissions from one tool to another are excluded through this approach. The suggested framework facilitates the linking of simulation tools, which were, "until now", developed independently from each other and which are specialized for certain production processes or methods, too. Furthermore, the integration of data generated in the course of the simulation is realized in a unified and process-oriented way. Apart from the integration of further simulation tools into an application that was already established, it is essential to extend the domain of simulations reflected upon with additional simulations covering the fields of machines and production. In this way, a holistic simulation of production processes is provided. Thereby, a major challenge consists in generating a central data model, which supports the possibility of illustrating data uniformly and in consideration of its significance in the overall context, which, in turn, comprises the levels of process, machines as well as materials. Due to the methodology presented, it is not necessary to adapt applications to the data model aforementioned. On the contrary, this step is realized via the integration application, which is to be developed on the basis of the framework. Because of the unified data view and the particular logging of data at the process level, the framework facilitates a comparison between the results of different simulation processes and simulation tools. Furthermore, conclusions can be drawn much easier from potential sources of error. This is a procedure, which used to be characterized by an immense expenditure of time and costs. In this context, the development of essential data exploration techniques on the one side and of visualization techniques on the other side turns out to be a further challenge.

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1 Introduction

Complexity in modern production processes increases continuously. Therefore, the virtual planning of these processes simplifies their realisation extensively and decreases their implementation costs. So far, several institutions have implemented their own simulation tools, which differ in the simulated production technique and in the examined problem domain. On the one hand, there are specialized simulation tools available simulating a specific production technique with exactness close to the real object. On the other hand, there are simulations which comprise production processes as a whole. The latter do not achieve prediction accuracy comparable to the one of specialized tools. However, both types are commonly applied in university research.

Furthermore most of the applied algorithms in these tools are not yet implemented in commercial tools. Hence, the simulation of a whole production process using these tools is often not realisable due to an insufficient prediction accuracy or the missing support of the asked production techniques. In solving the problem, it is necessary to interconnect different specialized simulation tools and to exchange their resulting data. However, the interconnection is often not achievable because of incompatible file formats, mark-up languages and models used to describe the simulated objects. Therefore, the simulation of a production process as a whole using different simulation tools is hard to realise because of the missing consistency of data and interfaces.

Therefore, results received within a simulation can only be integrated into another one after being checked manually and being adapted to the needs of following simulations, which is both tedious and fault-prone. On the one hand, the huge data volumes being characteristic for simulation processes are not supported by current solutions. On the other hand, the possibilities to adapt a simulation process as a consequence of changes (e.g. integration of a new application, modification of a simulated object) are poorly supported.

In this paper, the architecture of a framework for adaptive data integration is presented, which enables the interconnection of simulation tools of a specified domain. The framework provides generic functionality which, if customised to the needs for a specified domain (e.g. by transformation rules or data interfaces), supports the system to integrate any domain specific application in the process by making use of adaptive integration.

For this purpose, this chapter focus on the integration of data generated during the applications' usage, whereas the applications' link-up technique, which can be handled with the help of modern middleware techniques, will not be stressed. The framework is getting developed within the project "Integrated Platform for

Distributed Numerical Simulation", which is a part of the Cluster of Excellence "Integrative Production Technology for High-Wage Countries" at RWTH Aachen University.

2 State of the Art

Since the eighties, but at least since the nineties, data integration as well as Enterprise Application Integration (EAI) belongs to the most frequented topics across application boundaries [HRO06]. Today, a multitude of data integration products can be found which are used in different fields of application. In general, the functionality of those products can be sub-divided into three categories [Whi05] (cf. Fig. 1):

- Data propagation
- Data federation
- Data consolidation.

With regard to the operational section, Data Propagation is applied in order to make use of data on a cross-application basis, which is often realised via data propagation. As already presented in [Whi05], data propagation mainly focuses on small data volumes like messages and business transactions that are exchanged between different applications. In order to realize EAI, a contemporary architecture concept is used, which was developed in connection with service-based approaches [Cha04] and which will be emphasized within this contribution – the so called Enterprise Service Bus (ESB). The basic idea of ESB, which can be compared to the usage of Integration Brokers, comprises the provision of services within a system [Sch03]. Figure 2 illustrates the schematic structure of an ESB. Each service provides a technical or technological functionality with the help of which business processes are supported. All services are connected with each other via the Integration Bus. Transformation services provide general functions in order to transfer data from one format and model into another one. Against that, routing services are used to submit data to other services. Both transformation and routing services are used by adaptors in order to transfer data provided by the Service Bus into the format and the model of an application. Consequently, transformation services support the reuse of implemented data transformations. The advantage of a solution based on the ESB pattern is to be seen in the loose interconnection of several services, whereas the missing physical data interconnection can be regarded as a disadvantage [RD08]: If recorded data has to be evaluated or to be analysed subsequently (e.g. with the help of data exploration techniques like OLAP or Data Mining), it will have to be read out and to be transformed once again. According to this fact, a historic or at least long-term oriented evaluation of data is inconvertible. In order to realize a unified examination on a cross-data basis, other sections belonging to the field of data integration need to be taken into consideration (cf. Fig. 1). Data Federation, which is examined within

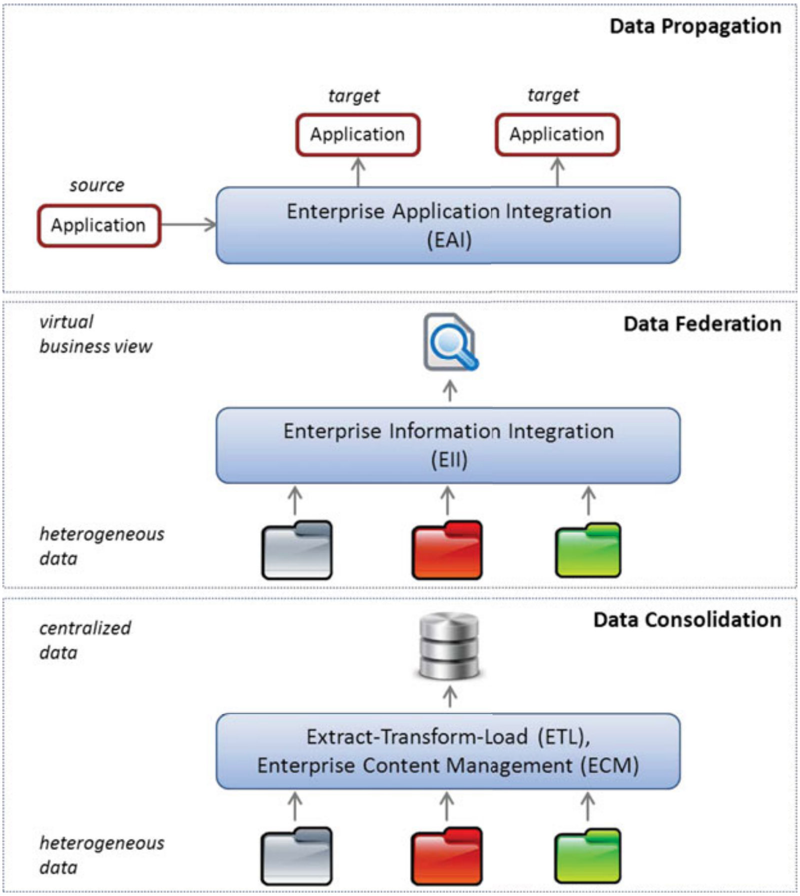

Fig. 1 Main areas of data integration

the field of Enterprise Information Integration (EII), might serve as one possible solution to enable a unified examination. With the aid of EII, data, which is stored in different data sources, can be unified in one single view [Whi05, BH08]. This single view is employed by the user to query this virtual, unified data source. The query itself is processed by the EII system by interrogating the underlying, differing data sources. Because of the fact that most EII do not support advanced data consolidation techniques, the implementation will only be successful if the data of the different data sources can be unified and if access to this data is granted (e.g. via query interfaces). Otherwise, techniques belonging to the field of data consolidation, which comprises the integration of differing data into a common, unified data structure, need to be utilised. Extract-Transform-Load (ETL) – a current process with regard to data integration – can be seen as one example of data consolidation [VSS02]. ETL consists of the following aspects: The extraction of data from one or several – mostly operational – data sources, the transformation of the data format as well as of the data model into a final schema and, finally, the uploading of the final schema to the target data base. The presented sections of data integration (and not just those) have in common that, independent of the type of integration, the heterogeneity of data has to be overcome. In literature, different kinds of heterogeneity are distinguished [KS91, Goh97]. In this chapter, the types of heterogeneity listed in [LN07] will be stressed:

- Technical heterogeneity
- Syntactic heterogeneity
- Data model heterogeneity
- Structural or schema heterogeneity
- Semantic heterogeneity.

The problem of technical heterogeneity, which addresses the problem of accessing data, can be handled with the help of modern middleware techniques [Mye02]. Syntactic heterogeneity, a problem arising as a result of the representation of data (e.g. number formats, character encoding), is solved by converting the existing representation into the required one; in most cases, the conversion is carried out automatically. The handling of data model heterogeneity is more complex, as this kind of heterogeneity can be traced back to data using different data models (e.g. relational database, XML data model, structured text file). Nevertheless, modern data integration solutions provide readers and writers to access data from popular data models like relational databases or XML. Besides that, the support of other data models can be implemented. The combination of both structural and semantic heterogeneity is the most complex form of heterogeneity. Structural heterogeneity addresses the problem of representing data in one data model in different ways, for instance the usage of element attributes versus nested elements in a XML document. Semantic heterogeneity comprises differences in meaning, interpretation and in the type of usage of schema elements or data. Schema and ontology matching as well as mapping methods can be used to find alignments between data schemas as well as to process these alignments. Thereby, an alignment is a set of correspondences between entities of schemas that have to be matched. In the past years, several matching and mapping algorithms have been published [ES07]. However, these methods often focus on database schemas, XML schemas and ontologies without taking into account the background domain specific information [GSY06]. This chapter will not take a closer look at the last point mentioned. A further approach to handle the heterogeneity of data consists in the a priori restriction of used tools within the considered simulated production process (cf. Sect. 3). The restriction to a kind of heterogeneity that is predictable via a set of simulation tools restricted beforehand implies a low flexibility that is provided by the corresponding architecture. The user may not employ the specialization of a single tool for a special purpose and is thus forced to disclaim qualified results in a special case.

3 Use Case

During procedures like the manufacture of a line pipe, different production techniques are put to use. Within the use case, these techniques are simulated via specialised tools. The use case starts with a simulation of the annealing, the hot rolling as well as the controlled cooling of the components via CASTs, an application developed by Access e.V. Within a further step, the cutting and the casting will be represented with the help of Abaqus (Dassault Systems), whereas the welding and the expanding of the line pipe will be simulated via SimWeld, a tool which was developed by the Welding and Joining Institute of RWTH Aachen University, and via SysWeld, a software product contrived by the ESI-Group [RM07]. Furthermore, the simulation of modifications in the micro structure of the assembly will be realized by making use of Micress [LNS98] and Homat [Las02], which were both developed by Access e.V. All in all, the use case contains six different kinds of simulations, each of them based on different formats and models. Apart from that, the project "Integrated Platform for Distributed Numerical Simulation" comprises four additional use cases, on which the requirements directed to the framework are based. Nevertheless, these use cases will not be stressed in the following. The requirements aforementioned were first examined and described in [SM09] and more detailed in [Sch10]. Two requirements, which turned out to be central with reference to the framework presented in this paper, are the possibility of Data Propagation and the necessity of a process-oriented Data Consolidation (cf. Fig. 1). Both of them are used to facilitate a subsequent visualization and analysis of data collected within the process. Another important demand concerns the implementation of the following aspects without having to adapt the application significantly: the illustration of new simulation processes as well as the integration of new simulation tools.

4 The Framework's Architecture

The framework's architecture is based on the Enterprise Service Bus' (ESB) architectural concept and thus follows the requirements described in Sect. 3. The architecture is illustrated in Fig. 2 (as described in [Cha04]).

In order to realise a communication process between the integration server and the applications, a middleware is used that encapsulates the functionality of routing services, which are typical of those ones used in ESB concepts (e.g. within the use case mentioned in Sect. 3, the application-oriented middleware Condor [TTL05] is employed).

Since a service does not provide any capability to communicate over messages it needs a further instance to undertake this task. This instance is the Service Activator. Each Service has its own Service Activator, whereas a Service Activator might also handle several Services. The Service Activator listens to the Integration Bus with the intention to identify any messages containing queries, which could be executed by one of the services the Service Activator cares about. Beside the query itself, the

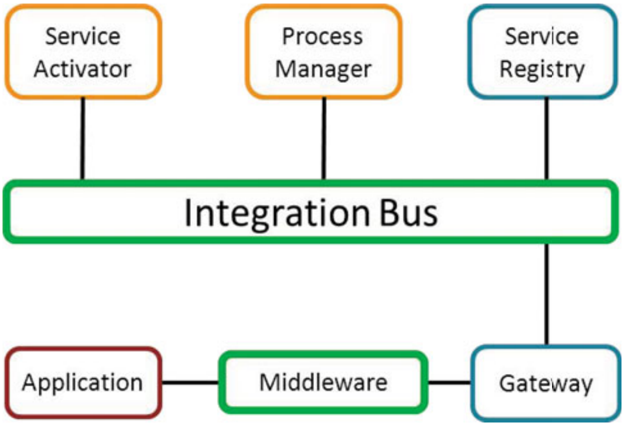

Fig. 2 The system-architecture of the framework

message contains also information about the requirements that need to be fulfilled by the service. In the case there is a query matching the capability of one of the services entrusted to the Service Activator's care, it locks one of its services to process this message and marks it as "in work", so that there is no other service processing this query. The procession's result is getting packed into a message by the Service Activator and is sent to the specified reply queue.

Each process within a simulated production process is managed by the Process Manager. It writes messages containing queries into the Integration Bus' Queue, so that processes can be executed by a service and it cares about the process initiation and eradication. The Integration Bus consists in particular of a queue containing the different queries the Process Manager writes into. The messages are read by at least one Service Activator.

Hence, routing services are not considered in this framework because the integration of standard middleware is straight forward. The framework is employed with the intention of realising an integration level at which service providers, which are directly linked to the Integration Bus, make different services available. Due to the fact that the integration architecture needs to allow the easy substitution of one application by another one, the choice of a service-oriented architecture was helpful, to obtain an adaptable solution. In the following, there will be a concise explanation of the architecture's components.

The services considered in this architecture comprise the following tasks: integration, extraction (both of them act as translators), analysis, transformation and planning. The Integration Services care about the processing of data for the further employment by making use of a particular application. That's why the Service Integration interface needs an own specialised implementation for each integration purpose. The Analysis Service checks the data that has been inserted into the database concerning their current structure as well as its semantics and the structure as well as its semantics requested by the next simulation tool within the simulated production process. Thereby it determines how the current data have to be transformed for the next step. To define the transformation steps needed to prepare the data, in a way that they can be processed by the next simulation tool within the simulated production process, the Analysis Service has to parse the message in order to know which processes are necessary to fulfil the requirements written into the message. Each implementation of the Transformation Service cares about exactly one special aspect in the existing data. This could be for example the indexing of nodes within a geometry. A necessary data model requirement for this purpose is the link between the node objects and "their" geometry object. There are applications starting the indexing for nodes with 0, whereas other applications start it with 1. Furthermore a random number might be determined during the creation of the geometry. By trying to interconnect two of those tools with each other the necessity is obvious to change the index of the existing data such that it can be understood by the next tool. Another example is the conversion of the temperature of a work piece from °C to °F.

In most cases, it is not sufficient to make more than one step to modify output data of one application such that they can be processed by the next application. An important constraint is the order in which these transformations have to be executed as a request exists to obtain a fully automated interconnection of applications on the one hand and the determining of the kind of transformations and their execution order on the other hand. At this point, Planning Services come into consideration.

They determine the kind of Services needed to perform the required operations and how these services have to interact. After their preparation by the appropriate, transformed data they get extracted by an Extraction Service. The Extraction Service cares about the extraction of data, which got recently processed by an application and is meant to get used by another one. In turn, the simulation results are stored within a file with a particular format. In certain cases it might be necessary to modify the input data. This step is called Enrichment.

Since the communication between all components is message driven the question arises, how to activate the adequate service for a certain task. The Process Manager controls the realisation of the current step by an appropriate service instance within a running integration or extraction process. It does not know which functionality can be provided by any service, not about the data a service needs to run. Thus there is the need for an instance having exactly this knowledge. This instance is called Service Registry. It contains information about available services, the functionality each service provides and which input data is required by each service to run properly.

A Gateway always belongs to a single application, which does not possess any capability to communicate with other architecture components over the Message Bus. The Gateway provides access for the architecture components to the application it belongs to and vice versa [HW04]. The described components, in particular the service oriented architecture allow to implement the concept of data integration in an adaptive way. This point will be considered in the following section.

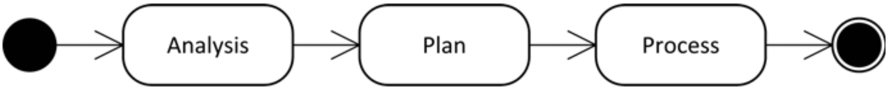

Fig. 3 The Enrichment Process

5 Adaptive Data Integration

The main goal of the adaptive data integration is to overcome the problems of structural and semantic heterogeneity. The adaptive data integration is part of the enrichment process step (cf. Sect. 4), which can be assigned to the extended ETL process being used during the extraction of data. The objective of the extraction process consists in the generation of data in a given data format, taking into account the data model and structure as well as the semantics of this format. Therefore, the implemented enrichment allows the discovery and exploitation of background-specific information. The concept is based upon ontologies and planning algorithms that are usually applied in artificial intelligence. The underlying enrichment process is depicted in Fig. 3. In the first instance, the existing data is analysed. The goal of the analysis is the determination of so-called features that are fulfilled by the data. A feature is domain specific, which means that it is expressing a structural or semantic property of the domain. Besides, the analysis step determines features that have to be fulfilled by the data to satisfy the requirements of the specific output format of the extraction process. Subsequent to the analysis, planning algorithms are used to find a data translation that transforms and enriches data in a way that allows for the fulfilment of features needed by the output format. After the planning is finished, the data translation, which is part of the executed step, is processed. The domain-specific data transformation algorithms are stored in transformation services following the ESB architectural concept, whereas the information about existing transformations and features is stored within an ontology. According to [Gru93], an ontology is an explicit specification of a conceptualization. In this chapter, the ontology-driven data integration will not be focused due to the limited space, which will not suffice to describe it in a proper way.

6 Application of the Framework in the Use Case

Within the domain of the use case described in Sect. 3 and the requirements resulting from the examination of four additional use cases in the domain of FE-simulations, an application has been implemented in parallel to the realisation of the

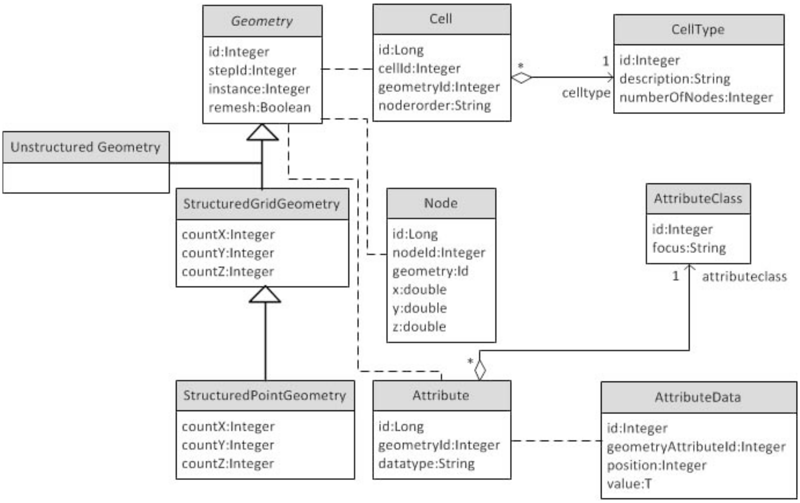

Fig. 4 Extract of the data schema used in the domain of FE-simulation

framework. The regarded applications are simulations that use the finite-element-method [ZTZ05]. With regard to the implementation of an application, which is based upon the framework, a domain specific data schema, adaptor services for the integration and extraction process, the transformation service, the data model and the domain ontology have to be provided. An extract of the implementation is presented in Fig. 4. The domain-specific data schema has been determined by analysing the different input and output formats of the simulations that were employed in the use case. Within this data schema, the geometry of the assembly can be regarded as the central entity. It consists of nodes, cells and attributes. The latter ones exhibit attribute values, which are assigned to individual cells or nodes depending on the class of attributes available in the whole geometry. The integration services, which were specified within the use case, read the geometrical data provided by the simulation, transform it into the central data model and upload the results into the database. In contrast, the extraction services proceed as follows: The geometrical data is read out from the central database and is transformed into the required format. Finally, the data is uploaded into the destination file or into the target database. Because of the prior enrichment, all structural and semantic data transformations have been carried out. Hence, most of the data transformations formerly performed by the adaptors' integration and extraction services are omitted.

Integration and extraction service: Most of these service adaptors have been implemented using the Pentaho Data Integrator (PDI). In case that more complex data or binary formats have been given, which can only be read by programming interfaces of the manufacturer, either the PDI functionality have been extended using the provided plug-in architecture or the needed functionality has been implemented using Java or C++. For example, the simulation results generated within the simulation tool CASTS are stored in the Visualization Toolkit (VTK) format [SML04]. Hence, an integration service was implemented, which is based on the programming interface supported by the developers of VTK using the provided functionality of the framework. Furthermore, an extraction service was developed with regard to the Abaqus input format, whereby, in this case, the aforementioned ETL tool PDI was used. Transformation library service: In order to realize the data integration, different sorts of data transformations for FE data were implemented into the application as services, for example the conversion of attribute units, the deduction of attributes from those ones that are already available, the relocating of the component's geometry within space, the modification of cell types within a geometry (e.g. from a hexahedron to a tetrahedron) or the aforementioned re-enumeration of nodes and cells.

7 Conclusion

The development of the framework presented in this chapter can be regarded as an important step in the establishment of digital production, as the framework allows a holistic, step-by-step simulation of a production process by making use of specialized tools. Both, data losses as well as manual, time-consuming data transmissions from one tool to another are excluded by this approach. The suggested framework facilitates the linking of simulation tools, which were, "until now", developed independently from each other and which are specialized for certain production processes or methods, too. Furthermore, the integration of data generated in the course of the simulation is realized in a unified and process-oriented way. Apart from the integration of further simulation tools into an application that was already established, it is essential to extend the domain of simulations reflected upon with additional simulations covering the fields of machines and production. In this way, a holistic simulation of production processes is provided. Thereby, a major challenge consists in generating a central data model, which supports the possibility of illustrating data uniformly and in consideration of its significance in the overall context, which, in turn, comprises the levels of process, machines as well as materials. Due to the methodology presented in this article, it is not necessary to adapt applications to the data model aforementioned. On the contrary, this step is realized via the integration application, which is to be developed on the basis of the framework. Because of the unified data view and the particular logging of data at the process level, the framework facilitates a comparison between the results of different simulation processes and simulation tools. Furthermore, conclusions can be drawn much easier from potential sources of error. This is a procedure, which used to be characterized by an immense expenditure of time and costs. The realization of this procedure requires the identification of Performance Indicators, which are provided subsequently within the application. In this context, the development of essential data exploration techniques on the one side and of visualization techniques on the other side turns out to be a further challenge.

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Digitale Produktion

Daniel Schilberg

Zusammenfassung Die in Deutschland und anderen Hochlohnländern produzierende Industrie ist angesichts der steigenden technologischen Leistungsfähigkeit der aufstrebenden Niedriglohnländer (China, Indien, Brasilien, Mexiko etc.) einem erhöhten Wettbewerbsdruck ausgesetzt. Um einen dauerhaften Wettbewerbsvorsprung gegenüber Niedriglohnländern zu sichern, muss die Forschung Technologien und Prinzipien entwickeln, die die Produktion in Hochlohnländern weiterhin wettbewerbsfähig halten. Ziel dieses Beitrages ist es, den Nutzen der digitalen Produktion mit Blick auf das Polylemma der Produktionstechnik darzustellen. In Bezug auf den internationalen Wettbewerb zielt die Digitale Produktion darauf ab, den Planungsaufwand der in Hochlohnländern produzierenden Industrie zu reduzieren. Für die Digitale Produktion sollen die zuvor erwähnten Simulationen in ein System integriert werden, um Herstellungsprozesse ganzheitlich vom Werkstoff bis hin zur Fabrik abzubilden.

Schlüsselwörter: Production Technology, Enterprise Application Integration, Virtual Production

1 Einleitung

Die in Deutschland und anderen Hochlohnländern produzierende Industrie ist angesichts der steigenden technologischen Leistungsfähigkeit der aufstrebenden Niedriglohnländer (China, Indien, Brasilien, Mexiko etc.) einem erhöhten Wettbewerbsdruck ausgesetzt. Diese Situation wird als verstärkter Wettbewerb wahrgenommen, da der wirtschaftliche Impuls bis in die 1930er Jahre von Europa und Nordamerika ausging [Cha04] und das daraus resultierende wirtschaftliche Gefälle zwischen den

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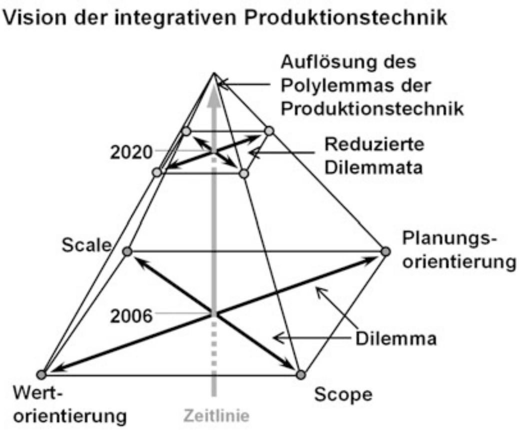

Abb. 1 Polylemma der Produktionstechnik

Nationen bis ins 21. Jahrhundert reicht [HHL09]. Eine Folge dieses Wettbewerbsdrucks ist die anhaltende Auslagerung der Güterproduktion zwecks Kostensenkung in diese Niedriglohnländer [SL05].

Soll dieser Trend wieder umgekehrt werden, müssen Konzepte entwickelt werden, die eine konkurrenzfähige Produktion in Hochlohnländern ermöglichen. Die dort produzierende Industrie sieht sich aber mit zwei Dilemmata kon-frontiert. Das eine Dilemma besteht zwischen der Massenproduktion mit sehr eingeschränktem Produktspektrum (Scale) [Sil87] und einem sehr großen Variantenreichtum bei geringen Stückzahlen (Scope) [PW81]. Das andere Dilemma bildet das Spannungsfeld zwischen der Planungsorientierung [Pfe96] und der Wertorientierung [WBHH04]. Die Eckpunkte dieser beiden Dilemmata spannen das sogenannte Polylemma der Produktionstechnik auf (Abb. 1). Um einen dauerhaften Wettbe-werbsvorsprung gegenüber Niedriglohnländern zu sichern, muss die Forschung Technologien und Prinzipien entwickeln, die dieses Polylemma verringern oder gar auflösen, wobei die singuläre Betrachtung eines Eckpunktes nicht ausreichend ist [SKBS07].

Der von der Deutschen Forschungsgemeinschaft (DFG) geförderte Exzellenzcluster „Integrative Produktionstechnik für Hochlohnländer" der RWTH Aachen University beschäftigt sich unter anderem innerhalb des Kernforschungsfeldes „Virtuelle Produktionssysteme" mit der Lösung dieses Polylemmas. Im Bereich der „Virtuellen Produktionssysteme" wird die Kopplung von in der Produktionstechnik eingesetzten Simulationen zu einer Simulationskette untersucht. Die zu koppelnden Simulationen umfassen u. a. Finite-Elemente-Simulationen und numerische Modellsimulationen zur Bewertung und Optimierung von Prozessen [SK97]. Die in den Simulationen verwendeten Modelle haben i. d. R. eine hohe technische Reife erlangt und eine isolierte Weiterentwicklung dieser Simulationen entspricht eher einer kontinuierlichen Verbesserung als weiteren Innovationen, die aber zur Lösung des Polylemmas nötig sind. Ein höheres Potenzial der virtuellen Gestaltung liegt in der Verknüpfung der Simulationen zu Prozessketten mit einer ganzheitlichen Gestaltungsaussage und Aufwand-Nutzen-Abwägungen [SK97].

Ziel dieses Beitrages ist es, den Nutzen der digitalen Produktion mit Blick auf das Polylemma der Produktionstechnik darzustellen. In Bezug auf den internationalen Wettbewerb zielt die Digitale Produktion darauf ab, den Planungsaufwand der in Hochlohnländern produzierenden Industrie zu reduzieren. Für die Digitale Produktion sollen die zuvor erwähnten Simulationen in ein System integriert werden, um Herstellungsprozesse ganzheitlich vom Werkstoff bis hin zur Fabrik abzubilden.

2 Das Polylemma der Produktionstechnik und die Digitale Produktion

Die Eckpunkte des Polylemmas der Produktionstechnik stellen Extremwerte der real existierenden Ausrichtungen innerhalb der Produktionstechnik dar. Das Polylemma betrachtet als Extreme zum einen eine rein wertorientierte Produktion ohne zentrale Planung und zum anderen eine planungsorientierte Produktion, bei der die Produktion zentral und detailliert vorab geplant wird. Des Weiteren existiert der Extrempunkt Scale, der die Massenproduktion, bei der es zu keiner Änderung des Produktionsprozesses kommt, betrachtet. Der mit Scope bezeichnete Extrempunkt schließlich repräsentiert eine Produktion, in der Produktionsschritte nur einmal zur Anwendung kommen [SKBS07].

Merkmale für eine wertorientierte Produktion sind zum Beispiel die Fokussierung der Produktion auf wertschöpfende Prozesse, die Minimierung des Aufwandes für Planung, Arbeitsvorbereitung, Handhabung, Transport und Lagerung und eine hohe Standardisierung der Arbeitsmethoden. Die planungsorientierte Produktion hingegen zeichnet sich durch einen hohen Planungsaufwand zur Optimierung wertschöpfender Prozesse, den hohen Einsatz von Simulations- und Modellierungswerkzeugen und das Management von Wissen und Information aus. Die Produktion im Bereich Scale ist durch eine hohe Anzahl herzustellender Produkte mit demselben Fertigungsprozess bei maximaler Taktrate, hoher Standardisierung und einer hohen Synchronisation der Prozesse geprägt. Die scopeorientierte Produktion ist gekennzeichnet durch wandlungsfähige Prozesse, einen begrenzten Durchsatz und eine begrenzte Synchronisation der Prozesse.

Wert- oder Planungsorientierung?

In produzierenden Industrieunternehmen werden planungs- und wertorientierte Ansätze innerhalb der technischen und organisatorischen Durchführung der Produktion eingesetzt. Die möglichst genaue Vorhersage des Produktionssystems und sein Verhalten stehen im Fokus des planungsorientierten Ansatzes. Dieser soll die Identifizierung des optimalen Betriebspunktes der technischen Anlagen und der organisatorischen Strukturen begünstigen und damit die Entscheidungsfindung unterstützen, wobei der Handlungsrahmen durch die Gesamtheit der Geschäftsprozesse im Unternehmen gebildet wird. Um einen planungsorientierten Ansatz anzuwenden, müssen Strukturen und Verhaltensweisen des betrachteten Systems oder Teilsystems durch Modelle genügend genau beschrieben werden. Diese Modelle müssen entweder automatisiert oder von Menschen verarbeitet werden können. Die Planungsergebnisse hängen in ihrer Qualität in erster Linie von der Umsetzung des Models und der damit zusammenhängenden Beschreibung des Ausgangs- und des Zielzustands ab. Für die Modellbildung ist daher, bezogen auf das zu beschreibende Produktionssystem, Transparenz der Geschäfts- und Produktionsprozesse erforderlich. Denn nur wenn die Ergebnisse und der Entstehungsprozess der Planung nachvollziehbar und bewertbar sind, können die Ergebnisse im Entscheidungsprozess richtig eingeschätzt werden. Für die Modellentwicklung, -auswertung und -bewertung ist ein hoher Ressourceneinsatz notwendig, der bei einem planungsorientierten Ansatz eine Aufwand-Nutzen-Abschätzung erforderlich macht [Pfe96, WBHH04].

Das Product Lifecycle Management (PLM), das Advanced Planning and Scheduling (APS), die Produktionsplanung und -steuerung (PPS) und das Enterprise Resource Planning (ERP) gehören zu den in der industriellen Praxis eingesetzten Informationssystemen, mit deren Unterstützung ein planungsorientierter Ansatz verfolgt wird [GW09]. Die Planung von Fertigungsprozessen und Produkten wird durch diese Informationssysteme unterstützt, indem das Informationssystem über die verwendeten Modelle die erforderlichen produktbezogenen Informationen bereitstellt. Durch die Simulation von alternativen Fertigungsverfahren und Produktionsprozessen unter Verwendung geeigneter Computersysteme und Algorithmen kann, schneller als der Mensch in der Lage wäre, alle Alternativen zu prüfen, eine nahezu optimale Lösung für die Herstellung eines Produktes gefunden werden.

Die zurzeit eingesetzten Softwaresysteme sind häufig nur auf die Anforderungen für die Abbildung eines bestimmten, klar definierten Prozesses oder Teilprozesses abgestimmt und daher auf ein Anwendungsgebiet beschränkt. Die Durchführung der zu planenden Prozesse ist hierbei eng mit der Planung vernetzt. Anpassungen an geänderte Rahmenbedingungen sind zeit- und kostenintensiv, da Interdependenzen zwischen Teilbereichen bei der Planung nicht berücksichtigt werden. Auch eine übertragbarkeit auf andere Anwendungsfälle ist in der Regel nicht möglich. Des Weiteren unterliegen die Informationssysteme einem dauerhaften, kontinuierlichen Optimierungsprozess für maßgeschneiderte Lösungen, die eine kritische Betrachtung des Verhältnisses zwischen Aufwand und Nutzen erfordern. Bei einer Fokussierung auf die Optimierung von Teilschritten des Gesamtprozesses ist es nicht möglich, ein planerisches Gesamtoptimum für das gesamte Produktionssystem zu identifizieren, da die eingesetzten Systeme eine Abweichung von der optimalen Teillösung zugunsten einer optimalen Gesamtlösung nicht zulassen. Alternativ zu einem rein planungsorientierten Ansatz mit hohen Kosten und Risiken kann auch eine Fokussierung auf die wertschöpfenden Prozesse vorgenommen werden. Dementsprechend reduziert das Lean-Production-Konzept [WJ04] als Vertreter des wertorientierten Ansatzes planungsbezogene Aktivitäten so weit wie möglich und lagert diese dem wertschöpfenden Prozess nicht mehr vor, sondern integriert sie. Gestaltungsansätze werden bei diesem Konzept meist dezentral umgesetzt und mit Konzepten der Selbststeuerung verbunden. Im Fertigungsprozess erforderliche Planungsaufgaben werden von dem für den jeweiligen wertschöpfenden Prozess verantwortlichen Mitarbeiter vor Ort durchgeführt. Die Grenzen derartiger wertorientierter Systeme liegen in der beschränkten Fähigkeit von Produktionssystemen zur Selbstorganisation (z. B. im Rahmen von Gruppenarbeiten). Des Weiteren besteht das Risiko, dass bei der Fokussierung auf die Wertschöpfung gewisse Optimierungspotenziale, die durch eine erweiterte Planung erschlossen werden könnten, unerkannt bleiben.

Unter Berücksichtigung der zuvor beschriebenen Ausgangssituation sollte das Ziel der produktionstechnischen Forschung die Vereinigung von planungs- und wertorientierten Ansätzen sein, um es zu ermöglichen, eine optimale Abstimmung dieser Ansätze zu finden. Dies würde es ermöglichen auf Basis des jeweiligen Produktionsprozesses auszubalancieren, wie hoch der Einsatz planerischer Aktivitäten sein muss, um eine hinreichende Qualität und Leistungsfähigkeit des wertschöpfenden Prozesses zu erzielen.

Im Folgenden wird dargestellt, wie die Digitale Produktion dazu beitragen kann, den Aufwand für den Einsatz von Planungswerkzeugen bei hinreichend genauer Darstellung des Gesamtprozesses und der Teilprozesse zu verringern und eine Reduktion des Dilemmas zwischen Planungs- und Wertorientierung ermöglicht.

3 Verringerung des Dilemmas zwischen Wert- und Planungsorientierung

Zur Verringerung des Dilemmas zwischen Planungs- und Wertorientierung wird im Folgenden eine Kennzahl entwickelt. Zu diesem Zweck werden alle Aufwendungen für die Planung unter dem Planungsaufwand zusammengefasst. Ein beispielhaft betrachteter Herstellungsprozess unterteilt sich in die Konzeptionsphase, die Produktplanung, Produktentwicklung sowie Prototyping umfasst, und die Produktionsphase, die sich in Prozesserprobung und -optimierung, Pilotserie, Vorserie, Nullserie, Produktionshochlauf und abgesicherte Produktion (Abb. 2) unterteilen lässt [Bis07]. Für die Betrachtung des Planungsaufwandes wird davon ausgegangen, dass die Ergebnisse der Planung sowohl bei der Planung ohne Einsatz der Werkzeuge der digitalen Produktion als auch bei der Planung mit Einsatz der Werkzeuge der digitalen Produktion die gleiche Qualität haben. Dies hat zur Folge, dass die Produktionsphase von Verringerungen des Aufwandes in der Konzeptionsphase entkoppelt [Bis07] und für die Entwicklung der ersten Kennzahl als konstant angenommen werden kann, so dass der Fokus der Betrachtung auf dem durch die Konzeptionsphase hervorgerufenen Aufwand liegt. Schon zu Beginn der Produktplanung entsteht durch die Analyse der Ist-Situation Aufwand. Bei der Analyse werden das Unternehmen, das Umfeld des Unternehmens und der Markt betrachtet. Hierbei müssen externe Impulse und die eigene Leistungsfähigkeit erkannt werden und die Markt- und Technologiesituation muss jeweils erfasst werden. Der Aufwand, der für die Durchführung der Situationsanalyse und die Erstellung der entsprechenden Dokumente entsteht, ist bei der Planungsdurchführung mit und ohne Einsatz der Werkzeuge der digitalen Produktion identisch. Nach der Auswahl von Produktide-

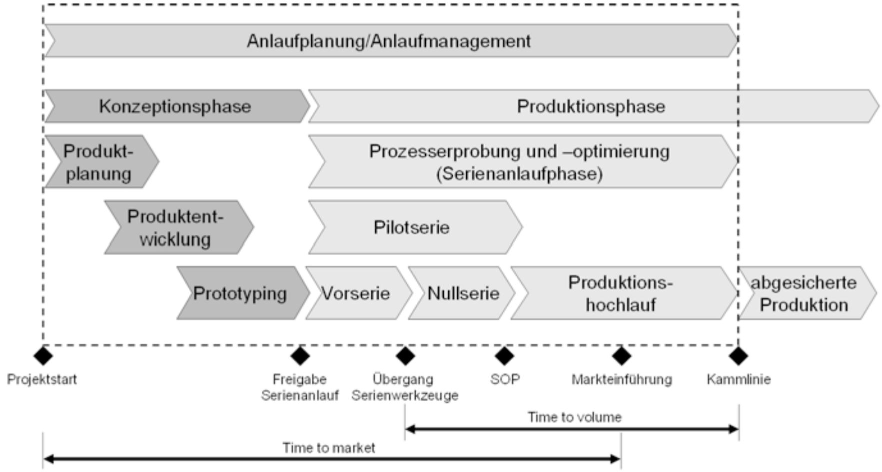

Abb. 2 Produktentstehungsprozess nach Bischoff [Bis07]

en findet die Produktdefinition und damit der übergang von der Produktplanung in die Produktentwicklung statt [SSS08]. Ab der Produktdefinition werden die Werkzeuge der digitalen Produktion in der Konzeptionsphase als Planungswerkzeug eingesetzt. Sobald die Produktdefinition durch Spezifizierungen der Funktionsweisen und Eigenschaften abgeschlossen ist, wird die Umsetzung geplant und es werden kurzfristige Entwicklungsziele vereinbart. Auf Basis der Spezifikationen und der vereinbarten Ziele entsteht das Lastenheft, auf dessen Basis das Pflichtenheft realisiert wird. Mit der Durchführung der Entwicklung und Konstruktion des Produkts schließt die Produktentwicklung ab und mündet in der Fertigung der Prototypen. Es ist zu erwarten, dass aus allen Teilen der Konzeptionsphase Rückführungen vorliegen. So haben Erkenntnisse aus der Produktentwicklung Auswirkungen auf die Produktplanung und Erfahrungen, die beim Prototypenbau gesammelt wurden, haben rückwirkenden Einfluss auf die Produktentwicklung und -planung.

Nachdem nun im Groben die Konzeptionsphase skizziert wurde, wird im Folgenden beispielhaft die Konzeptionsphase für den Herstellungsprozess eines Getriebezahnrads ohne den Einsatz der Werkzeuge der digitalen Produktion betrachtet. Im Anschluss wird herausgestellt, an welchen Stellen des Planungsprozesses die Werkzeuge der digitalen Produktion eingesetzt werden können und welchen Effekt dieser Einsatz auf den Planungsaufwand hat. Die Produktplanung ist zu diesem Zeitpunkt bereits so weit fortgeschritten, dass festgestellt wurde, welches Produkt mit welchen Eigenschaften am Markt angeboten werden soll. Es ist jedoch noch nicht festgelegt worden, mit welchen Teilprozessschritten das Getriebezahnrad gefertigt werden soll oder mit welchem Material die geforderten Eigenschaften am günstigsten und im ausreichenden Umfang erreicht werden. Zur Erfüllung dieser Aufgaben werden Experten und Simulationen eingesetzt, die das Erreichen eines optimalen Ergebnisses gewährleisten sollen. Die simulationsgestützte Definition des Fertigungsprozesses durch die Experten umfasst drei Punkte, die rückwirkungsbehaftet sind. Der erste

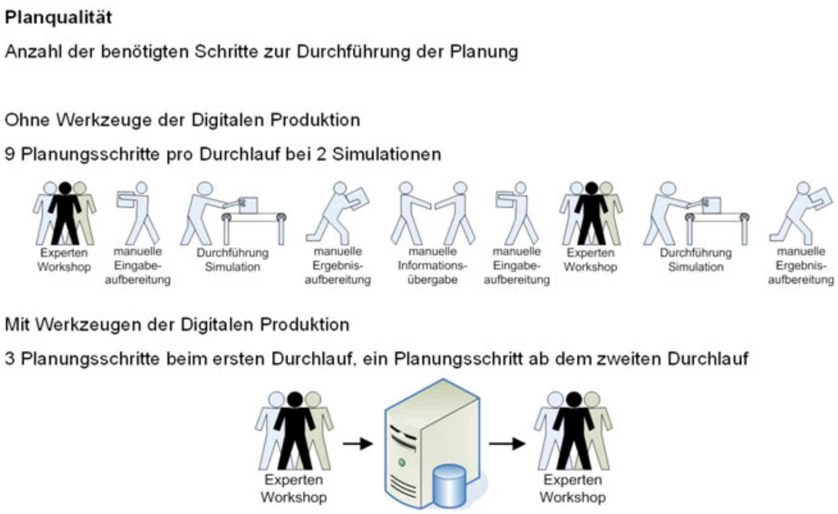

Abb. 3 Durchführung der Planung

Punkt umfasst die Auswahl des Werkstoffes, der zweite die Festlegung des Produktionsablaufs und der dritte die Auswahl der Werkzeuge für den Produktionsablauf.

Bei der Auswahl des Werkstoffes werden Simulationen auf Mikrostrukturebene eingesetzt, um die Materialeigenschaften zu ermitteln. Hierbei wird durch die Experten nicht nur geprüft, ob der Werkstoff die Anforderungen an das Produkt erfüllt, sondern auch welchen Einfluss der gewählte Werkstoff bzgl. der Verarbeitbarkeit und der Rohstoffkosten auf den Fertigungsprozess hat. So hat die Verarbeitbarkeit beispielsweise einen direkten Einfluss auf die zur Bearbeitung des Werkstoffes auszuwählenden Werkzeuge. Nach der Auswahl des Werkstoffes ist dessen Betrachtung jedoch nicht abgeschlossen. Da jeder Verarbeitungsschritt die Werkstoffeigenschaften und damit die Produkteigenschaften verändert, müssen die Werkstoffeigenschaften nach jedem Wärmebehandlungs-, Umform- und Fügendenprozess erneut betrachtet werden, um sicherzustellen, dass die Produktanforderungen weiterhin erfüllt werden. Dies zwingt die Experten für den Werkstoff ihre Daten mit den Daten der jeweiligen Experten für die Fertigungsschritte nach jedem Fertigungsschritt abzugleichen. Des Weiteren müssen die Experten für die einzelnen Fertigungsschritte die Daten nach Durchführung der jeweiligen Simulation für die Folgesimulation manuell aufbereiten. Die Aufbereitung der Daten kann nur im Dialog der Simulationsexperten geschehen, da z. B. der Experte für die Umformsimulation nicht weiß, welche Daten der Experte für die Fügesimulation benötigt. Abbildung 3 zeigt den Ablauf und die benötigten Experten-Workshops (EWS), die zum Datenabgleich bei einer manuellen Kopplung der in dieser Planungsphase eingesetzten Simulationen benötigt werden. In einem ersten EWS wird der einzusetzende Werkstoff ausgewählt, dessen Eigenschaften mit einer Mikrostruktursimulation bestimmt werden. Die aus der Mikrostruktur ermittelten Ergebnisse werden in weiteren EWS an die

Experten für die Fertigungsschritte übergeben, nach jeder Mikrostruktur- bzw. vor jeder Makrostruktursimulation sind weitere EWS notwendig. Nach der Auswahl des Werkstoffes wird die Prozesskette bestimmt, in der aus dem Werkstoff das Getriebezahnrad gefertigt wird. Diese gibt vor, welche Makrostruktursimulationen in welcher Reihenfolge und welche weiteren EWS durchgeführt werden müssen, um die Informationen zwischen den Makrostruktursimulationen zu übergeben. Dieser Ablauf mit allen EWS muss bei jeder Durchführung der Prozesskette auch bei der kleinsten Parametervariation erneut durchgeführt werden. Dies führt, z. B. bei der Bestimmung eines geeigneten Materials, zu einem sich immer wiederholenden iterativen Durchlaufen der Arbeitsschritte, das zwar mit der Zeit bei den Experten zu einem immer höheren Verständnis für die anderen Simulationen und die gesamte Prozesskette führt, den Bedarf nach EWS aber nicht senkt.

Durch den Einsatz der Werkzeuge der digitalen Produktion ist im Vorfeld, d. h. bevor die Prozesskette definiert und das Material ausgewählt werden kann, eine signifikante zusätzliche Arbeit zu leisten. Die Simulationen müssen mit einer vollständigen Beschreibung der Parameter hinsichtlich Bedeutung, Bezeichnung und möglichem Wertebereich in die Simulationsplattform integriert werden. Dies entspricht vom Aufwand her für jede eingesetzte Simulation einem EWS aus der manuell gekoppelten Prozesskette. Nach der Integration aller benötigten Simulationen müssen EWS nur jeweils einmal für die gesamte Prozesskette durchgeführt werden, danach kann die gesamte Prozesskette auch bei Variation des Materials, einzelner oder mehrerer Parameter automatisiert und ohne Eingriffe der Experten in die Prozesskette durchgeführt werden.

Der Planungsaufwand für diesen Teil der Konzeptphase lässt sich wie folgt beschreiben:

$$\begin{aligned} &\textit{Planungsaufwand} \\ &\textit{Planungsaufwand} = \textit{Anzahl EWS} + \textit{Durchführung der Simulationen} \\ &\qquad\qquad\qquad + \textit{Werkstoffauswahl} + \textit{Auswahl Prozesskette} \end{aligned} \tag{1}$$

$$\begin{aligned} &\textit{Kennzahl Planungsaufwand}\ (\mathrm{K_{PA}}) \\ &\mathrm{K_{PA}} = -\frac{\mathrm{PA_m}}{\mathrm{PA_o}} \end{aligned} \tag{2}$$

PA_m: Planungsaufwand mit Einsatz der Werkzeuge der digitalen Produktion

PA_o: Planungsaufwand ohne Einsatz der Werkzeuge der digitalen Produktion

Mit dieser Kennzahl ist es möglich, den Beitrag der Digitalen Produktion zur Reduktion des Dilemmas zwischen Planungs- und Wertorientierung darzustellen. Das Ziel ist es, bei einem hohen Einsatz von Planungswerkzeugen das Produktionskonzept dem der Wertorientierung anzunähern. Dieses Ziel kann nur erreicht werden, wenn die Planungswerkzeuge im Planungs- und Herstellungsprozess mit geringem Aufwand eingesetzt werden können und damit der Anteil der Arbeitszeit, die für die

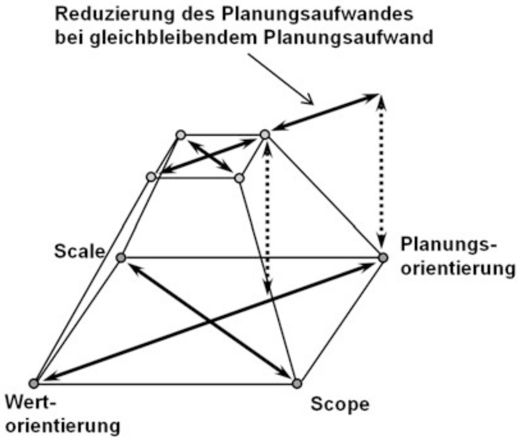

Abb. 4 Reduzierung des Planungsaufwandes

Arbeitsvorbereitung zur Verfügung steht, bei gleichbleibender Qualität verringert werden kann. Die Kennzahl für den Planungsaufwand hat gezeigt, dass der Aufwand für die Durchführung der Planung gegenüber der bisherigen weitestgehend manuell gekoppelten Planung deutlich reduziert werden konnte. Abbildung 4 zeigt den Beitrag der Digitalen Produktion zur Reduzierung des Polylemmas qualitativ. Die Achsen stellen in dieser Abbildung qualitativ den anteiligen Aufwand dar, der erbracht werden muss, um einer Orientierung zu entsprechen. Die Planungsanteile in der Produktplanung werden durch den Einsatz der Digitalen Produktion nicht verringert, unter Umständen wird dieser sogar erhöht. Der Aufwand für den Einsatz der Planungswerkzeuge jedoch wird reduziert.

4 Zusammenfassung und Ausblick

Die Digitale Produktion umfasst als Werkzeug die virtuelle Planung des Produkts durch CAD-Systeme, die virtuelle Modellierung der Maschinen, die das Produkt herstellen, die virtuelle Planung des Herstellungsprozesses, in dem die Maschinen genutzt werden, um das Produkt zu fertigen und die virtuelle Fabrikplanung, in der festgelegt wird, wie die Herstellung des Produktes räumlich und zeitlich unter Einsatz der Fertigungsanlagen, der Rohstoffe und weiteren Ressourcen aussehen soll [Paw08]. Die Werkzeuge der digitalen Produktion sollten nun dahingehend erforscht und weiterentwickelt werden, dass sie in eine Anwendung integriert werden können, um die reale Fertigung eines Produkts vollständig computergestützt planen und simulieren zu können. Abbildung 5 bietet ein Schema zur Verortung des vorgestellten Fertigungsprozesses Getriebezahnrad in den Dimensionen Domäne und Anzahl der Simulationen (n). Die Domäne bezeichnet das Einsatzgebiet der im Planungsprozess eingesetzten Simulationen. Diese werden im Beispiel der Domäne

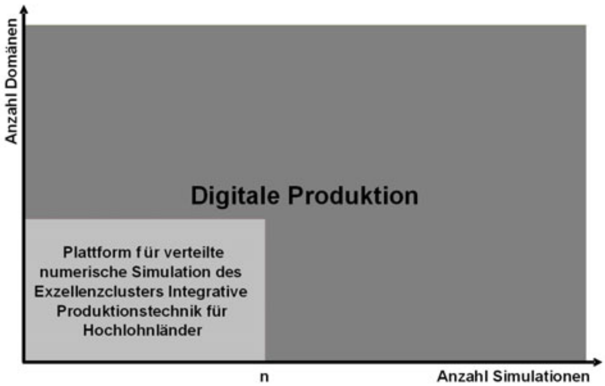

Abb. 5 Einordnungsschema von Herstellungsprozessen nach Domäne und Anzahl der Simulationen

der Materialverarbeitung zugeordnet. Mit dem Ziel der ganzheitlichen Realisierung muss die Digitale Produktion konsequent um weitere Domänen und Simulationen erweitert werden.

Zu diesem Zweck müssen die Elemente der Digitalen Produktion um die syntaktischen und semantischen Besonderheiten der jeweiligen Wissensdomänen erweitert werden.

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Enterprise Application Integration for Virtual Production

Daniel Schilberg, Tobias Meisen, Philippe Cerfontaine, Sabina Jeschke

Abstract The focus of this work is to promote the adoption of Enterprise Application Integration (EAI) as a framework for virtual production. The product planning phase in real and virtual production usually requires a huge range of various applications that are used by different departments of a company. To increase productivity on the one hand and reduce complexity of application integration on the other hand, it is essential to be able to interconnect the differing syntax, structure and semantics of the distributed applications. The presented EAI framework will be used in the production planning process of a Line-Pipe as a use case. The successful application interconnection in this use case is used to validate the framework.

Key words: Production Technology, Enterprise Application Integration, Virtual Production

1 Introduction

The combined and integrated use of heterogeneous software systems, to map processes along the value chain, is made possible through the use of a so-called Enterprise Application Integration (EAI) framework. EAI combines planning process oriented software systems and process descriptions to a single system. To connect the different software systems, the actual source code does not need to be changed. Instead, the interconnection is realized through the use of adapters. This enables the operator to use the software systems either as an individual program or as a part of a program chain via a single man-machine interface. The utilization of program

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chains allows the mapping of simulated processes to the corresponding business processes.

Presently, EAI is primarily used in manufacturing companies to depict recurring, semi- or fully-automated business processes. However, existing frameworks do not consider the integration of software systems that are found in the planning areas of materials and processing techniques. Thus, during the manufacture of a commodity, the depiction of a business process is neglected. Consequently, implications on the overall process and other important details derived from the production process are lost. If the aim is to picture the production of a commodity from raw material to a finished product in order to identify the majority of implications, the contemplation of the business process is not sufficient. In fact, the realization of this aim requires a continuous modelling of the process from the raw material to the finished product.

Simulations already exist for most of the manufacturing processes in the production of goods. These include, for example, welding, forming or heat treatments. Those simulations are usually isolated solutions, which have no common interfaces or data formats. Right now, existing systems do not address the interconnection of these simulations. As a consequence, simulation chains modeling manufacturing processes as part of virtual production are not adequate, because implications e.g. from the first simulation on following simulations are not considered. Therefore, a framework is needed to facilitate the interconnection of the simulations to simulation chains.

In this paper a framework is presented, which is capable of interconnecting heterogeneous distributed simulations to form simulation chains. This contribution focuses on interweaving the syntactic and semantic incompatibility of the previously mentioned simulations. The framework uses an ontology to match the different representations of names and the underlying concepts as well as relationships between the concepts. The concepts and relationships are stored in a strongly abstract manner in a top level ontology. Domain specific ontologies are used for the representation of concepts and relationships of certain simulations. The validation of the framework is established by virtually representing the manufacturing process of a Line-Pipe.

2 Problem

A multitude of manufacturing steps in the production process of goods are described by numerical simulations. Today an examination of a production process is based on singular consideration of the manufacturing steps without interlinking. This results in the problem that the single results of the simulations are not directly set in context of the entire production process. Figure 1 shows the production process of a Line-Pipe as an interlinkage of multiple manufacturing steps. The production process consists in detail of a series of heat treatments, forming processes, machining and joining techniques. Each of these production steps is represented by a numerical simulation. The models for each domain (e.g. joining) used in the simulations

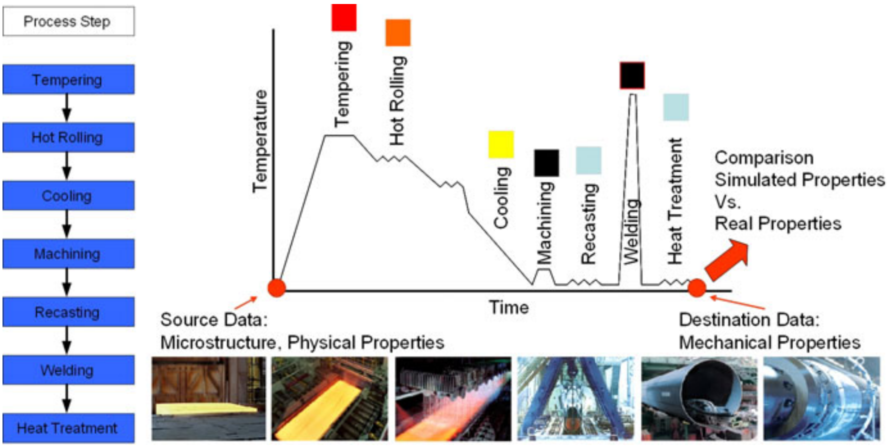

Fig. 1 Production process of a Line-Pipe

are based on corresponding expert knowledge. Usually, these simulations are isolated applications that do not have common interfaces and data formats. In addition, the simulations calculate with different physical scales: The metal forming, machining and the joining simulations examine macrostructure changes, while the heat treatment simulation process changes the microstructure, e.g. modifications of material properties. In existing planning processes the interconnection of simulations to simulation chains to map a whole production process, covering diverse scales and knowledge domains, is not considered sufficient. Therefore it is necessary to combine the simulations context sensitive. To apply simulations interconnected as simulation chains, an integration tool is needed that realizes the interlinkage of the various simulations [Sch10].

EAI is developed to establish application interconnection on the level of business processes. In the following section (Sect. 3) the current state of the art of EAI frameworks is presented. Subsequently, a tool for data integration is introduced (Sect. 4). The tool enables the user to realize the interconnection of heterogeneous numerical simulations. The production process of a Line-Pipe is used for the validation of the introduced data integration tool (Sect. 5). The paper concludes with a summary and outlook on further development opportunities.

3 State of the Art

EAI can be understood as a comprehensive concept that includes a complete set of business processes, management functions and organizational interactions for performing, controlling and monitoring. As a holistic process, EAI designs seamless high-agile processes and organizational structures that match the strategic and economic concept of a company.

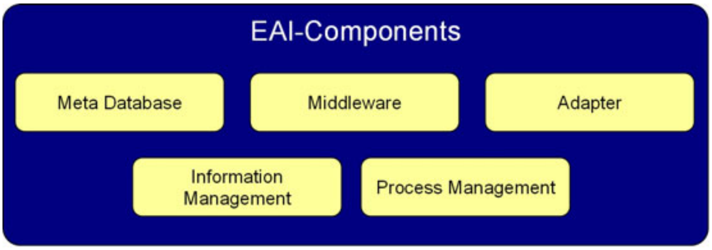

Fig. 2 EAI components

Systems in which EAI concepts are used are characterized by integrative, progressive and iterative cycles of technology, labour force, knowledge and operational processes usage [Mye02]. Observing information technology systems used for the implementation of EAI, the term becomes more clarified and concrete: EAI is understood as a software tool for integrating heterogeneous systems [Bas]. Common EAI frameworks consist of the components meta database, middleware, adapters, message management and process management (see Fig. 2) to provide the claimed functionality [Hoh02]. Important references concerning the EAI modelling are given in the works of Linthicum, Ruh, Cummins, O'Rourke and Whitten [Lin00, RMea01, Cum02, OFS03, WBD04].

- The middleware is designed to manage adapters and resources and to provide auxiliary services.
- The adapters realize the connection between the different to be integrated applications and the middleware. Two types of adapters are used, a static (fixed implementation) and a dynamic (configurable) adapter. Both should overcome the incompatibilities that result from both the syntactic and the structural heterogeneity of the applications. The static adapters are developed and used in a context that does not change. The dynamic adapters are used in a changing context and have to be reconfigured depending on the use case.
- The meta database is the central storage of information concerning the distribution of components. Information about the safety parameters, responsibilities, technological infrastructure, communications patterns, transformations, rules and logic for processing messages, architecture and design are stored and managed.
- The information management provides transformation and synchronization services and ensures the transactional of transformation operations. The information management component overcomes on the one hand the constraints of syntactic and structural heterogeneity and on the other hand the semantic heterogeneity.
- The process management controls and administers process modelling, process control and process steering. Running and interruptible semi-automated business processes are supported by the process management. Furthermore, the process management takes over the process monitoring and reporting [Hoh02].

Table 1 EAI Frameworks

EAI Framework	Proprietary or Open Source	Data Scheme/Model	Miscellaneous	FE Data
Oracle Application Server Interconnect	Proprietary	Common XML based data model	Oracle BPEL PM, Oracle Enterprise Bus, etc. extensions	No
IBM WepSphere Product Suite	Proprietary	Common XML based data model	Message Broker, Event Broker, Message Queue, Process Server, etc.	No
JBoss	Open Source	JBoss conform XML Message System	JBoss Application Server and JBPM extensions	No
Open Adapter	Open Source	Java Objects		

Current EAI Framework solutions are presented in the following. Two proprietary (Oracle and IBM) and two open-source frameworks (JBoss, Open Adaptor) will be compared. The selection is not a substantive review but based on the wide distribution of the frameworks. Table 1 gives a brief overview of the mentioned EAI frameworks.

3.1 Oracle Application Server Interconnect

The EAI Framework Application Server Interconnect is developed by Oracle. It uses a XML-based common data schema and model for the application integration. The applications that should be integrated are connected to the framework by using an integration logic. This logic creates integration points that are stored in a meta database and that are linked to the common data model. The integration of the respective application happens event driven. Here, the applications are assigned to an integration point defined by an event. Whereby, the overall process can be represented via the EAI framework by using the interconnected applications [ora].

3.2 IBM WepSphere Product Suite

The IBM WebSphere Product Suite provides a collection of tools such as Message Broker, Event Broker, Message Queue and Process Server for linking applications. This product uses a common data schema and model that is based on XML as well. To realize connections on the data layer via protocols such as FTP, HTTP, etc. the suite provides adapters. Graphical programming is used for the user interface. There configurable blocks can be linked in order to program an application integration [ibm].

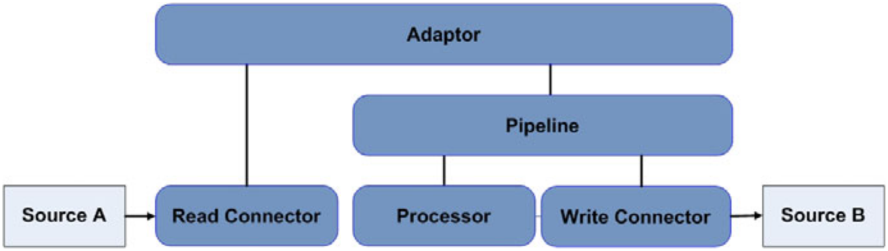

Fig. 3 OpenAdaptor interconnection scheme

3.3 JBoss

Also JBoss uses XML messages for communication within the framework. The EAI framework is developed in Java Open Source. Applications are integrated into the framework via adapters. To ensure the communication along the described process JBoss compliant XML messages are generated by the respective adapters. For links to resources such as Internet, databases, etc. connectors are implemented [jbo].

3.4 OpenAdaptor

OpenAdaptor does not provide a framework for application integration, but individual adapters, with which isolated applications can be interconnected. Provided standard adapters can be configured via XML for the integration of a particular application. Java objects are used for data exchange between applications. These are implemented in the adapters. The scheme in Fig. 3 shows the coupling of two applications with OpenAdaptor using a reading, a writing and a processor component [ope].

The main objective of the presented frameworks and solutions for application integration is the interconnection of the applications along a business process and the provision of an integrated solution. Here XML is often used to ensure a common data schema and model map. For the manufacturing process outlined in Sect. 2 and due to the large amount of structured finite element (FE) data, XML is not appropriate as base for a common data schema or model, because of the slower processing speed as a FE optimized data format like e.g. VTK [vis]. In addition, EAI frameworks are designed to achieve semantic linkage to applications of the same or a related knowledge domain [LOP05]. For the use case described in Sect. 5, it is necessary to realize a semantic integration along many knowledge domains. In the following section the designed Data Integrator for cross-domain semantic interconnection is presented. The Data Integrator is developed at the ZLW/IMA at RWTH Aachen University.

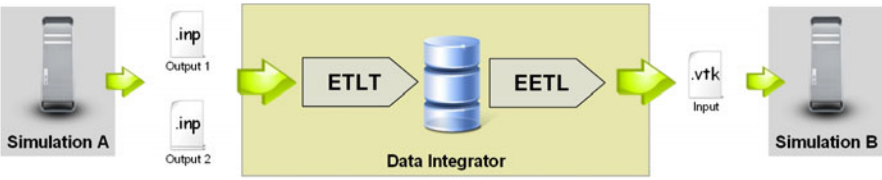

Fig. 4 Data integration scheme of the Data Integrator

4 Data Integration

The developed Data Integrator uses for the application interconnection the simulations input and output as files. The outputs of the applications as well as additional manual inputs are integrated via an Extract-Transform-Load-Transform process (ETLT process) into the common data storage. The required input data for an application is extracted with an Enrich-Extract-Transform-Load process (EETL process) from the common data storage [Whi05]. Figure 4 shows schematically how two simulations will be combined to an integrated solution. The common data storage is realized by using a database. This has to be treated analogous to the data schemas and models of the frameworks presented in Sect. 3 [MSH09]. Among others the ETLT and EETL processes take over the tasks of the adapters and connectors that are mentioned in Sect. 3. In the following, the functioning and the main objective of these two processes will be explained in detail.

In the first step of the ETLT process the data of sources present will be extracted (extract). Extraction sources can be files or input via a human-machine interface. Then, the extracted data is transformed into the data model that is represented in the database (Transform). This implies for the usage of finite element data, that the node, element and attribute information has to be indicated and named. Therefore a semantic mapping of the meaning of the identifiers is required. After this, the data is stored in the database (Load). The successful validation of the integrated data in a post-processing is the conclusion of the ETLT process.

Via the EETL process data can be extracted from the database by using a series of sub-processes for a source. The first sub-process will either convert the data in the required format or generate the required data out of existing data (Enrich). The functionality of the enrich process is shown in Fig. 5.

Data as temperature, strain, stress, cross-sectional area and length of a component is stored in the database. The target source of the example described in Fig. 5 requires the temperature in K, the modulus of elasticity and the spring constant. The temperature can be migrated directly, but the modulus of elasticity and the spring constant has to be generated by using transformations. After that, the data are to be extracted from the common data storage (Extract), to be subsequently brought into the required structural form (Transform). The last sub-process is the writing of the required input file (Load) for the target source. The meanings of each field stored in the database are used for the data mapping. The meanings are related to the corresponding application. Therein the processes for application integration used by the

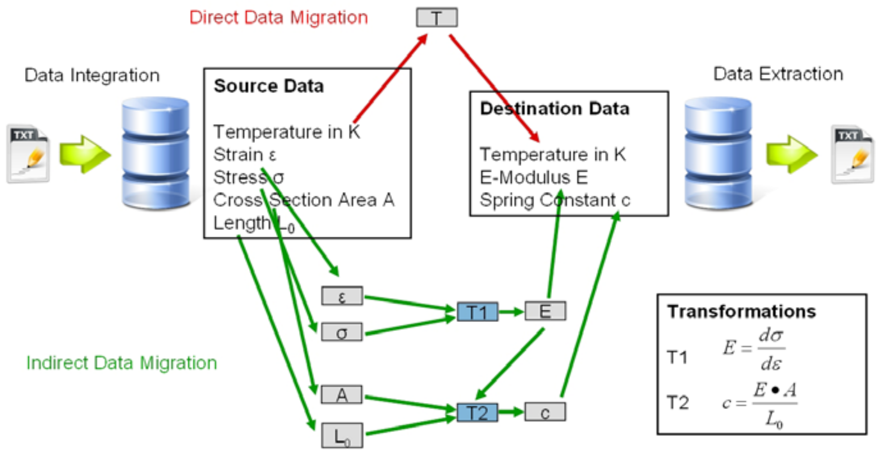

Fig. 5 Enrich process

Data Integrator are described. In the following, a brief demonstration of the integration process of heterogeneous numerical simulations is given, where the continuous manufacturing process of a Line-Pipe will be simulated as a use case.

5 Use Case

For the validation of the Data Integrator presented in Sect. 4, the simulation of the manufacturing process of a Line-Pipe (see Fig. 1) as use case is realized. Here, simulations which consider changes at the macro level and microstructure simulations are linked to a simulation chain. The application flow is to be automated. All input data are entered either on initialisation or generated during runtime from the available input and output data by the Data Integrator. After every process step on the macrostructure level a microstructure simulation is performed. The results of the microstructure simulation are used by the macrostructure simulations as input data. A homogenization application comes into operation to condition the microstructure simulation results for further computing by the macrostructure simulations. Also, the simulations which are developed as stand-alone solutions have no common interfaces. Furthermore, input and output of the simulations differ in syntax (differences in the technical presentation of information), structure (differences in the structural representation of information) and semantics (differences in the meaning of used terms and concepts). To simulate the entire manufacturing process five applications are used in the following order (see Fig. 1 and Table 2): The first software CASTS (developed by ACCESS e.V.) is used to simulate tempering. Then the forming simulation LARSTRAN (developed by the Institute for Metal Forming (IBF), RWTH Aachen University) is used to present the hot rolling process. The following cool-

Table 2 Line-Pipe Manufacturing Process

Process Step No.	Software	Process Step	Publisher
1	CASTS	Tempering	ACCESS e.V.
2	LARSTRAN	Rolling	IBF, RWTH
3	CASTS	Cooling	ACCESS e.V.
4	CASTS	Machining	ACCESS e.V.
5	ABAQUS	Recasting	Dassault
6	SimWeld	Welding	ISF, RWTH
7	CASTS	Heat Treatment	ACCESS e.V.
8	MICRESS	Microstructure Analysis	ACCESS e.V.

ing process and the machining for weld prep are simulated again with CASTS. The forming of the metal sheet into a tube is calculated with ABAQUS, a development of Dassault. The Institute of Welding and Joining (ISF) of the RWTH Aachen University provides a welding simulation called SimWeld to represent the penultimate process step. The final step in the simulated production process of the Line-Pipe manufacturing is the expansion (heat treatment), which again is represented by the application CASTS.

After each of these steps a microstructure simulation is performed with the software MICRESS (ACCESS e. V.) to create better input data for the macrostructure simulations [LNS98]. With the application HOMAT (ACCESS) the microstructure data is homogenized [Las02] for the use at macrostructure level.

The main problem during the realization of the automated simulation chain was the identification of the relevant data, which has to be passed from one simulation to the next because not all information is important for all simulations. But the used Data Integrator [Sch10] was able to provide the needed data.

6 Conclusion and Outlook

The Data Integrator can be used automatically in conjunction with a middleware [TTL05, CBKB08]. Then the Data Integrator reads the input and output files of the previously mentioned simulations. Additional it understands and generates new files according to the schemes presented in Figs. 4 and 5. Therefore, all parameters that can not be generated by the process must be known in addition to the input file of the first simulation (CASTS – tempering).

In this paper a tool for integrated automated interconnection of applications was presented. The Data Integrator is based on the general concepts of EAI [Hoh02] and was validated against the simulated manufacturing process of a Line-Pipe. It represents an important element in the realizing process of a virtual production. In addition to the virtual representation of factories and plants the Data Integrator enables a clear and step by step presentation of the manufacturing processes. For example different simulation models can be linked to an overall process across scales by using the Data Integrator.

A next step towards virtual manufacturing is the integration of all simulations that are used in the design and manufacturing of products. This means that not only machinery but also process simulations and factory planning tools are taken into account, which results in the following key challenges: integration of other knowledge domains along the vertical axis and extending the opportunity for additional mappings of syntax, structure and semantics. The long term objective is the establishment of vertical integration of the simulations next to the horizontal in order to enable the user to get an integrative view from raw materials through the material processing up to the manufacturing factory.

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Simulation and Interoperability in the Planning Phase of Production Processes

Daniel Schilberg, Tobias Meisen, Rudolf Reinhard, Sabina Jeschke

Abstract Interoperability is a progressive issue in the development of holistic production process simulations that are based on stand-alone simulation interconnections. In order to tackle the problem of missing interoperability, the standardization of simulation and model interfaces and transfer protocols can be taken into account. This procedure is endorsed by many organistaions like DIN ISO, IEEE, ASME or SISO and one of the most effective proceedings if a new simulation is developed and if the source code of the used simulations is available as well as changeable. However, as most simulations for a holistic production simulation already exist and as those simulations are usually isolated, high precisely solutions, which have no common interfaces for interconnection, a different approach is needed. The contribution at hand focuses on a framework that provides adaptive interfaces to establish interoperability of stand-alone simulations.

Key words: Production Technology, Simulation, Interoperability

1 Introduction

By reason of low costs, production in low-wage countries has become popular in the last few years. To slow down the trend of outsourcing production to low-wage countries, new production concepts for high-wage countries have to be created. Therefore today's production industry in high-wage countries is confronted with two dichotomies: value orientation vs. planning orientation as well as economies of scale vs. economies of scope.

Developing new concepts means to overcome the polylemma of production, shown in Fig. 1, which summarizes the two dilemmas mentioned above. Future-

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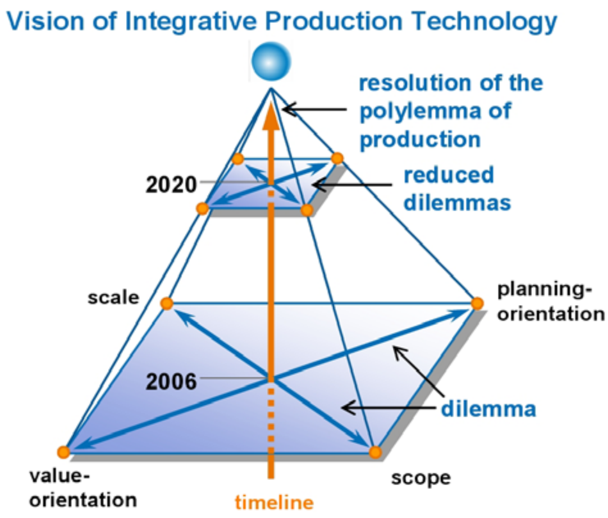

Fig. 1 Polylemma of production

proof production systems have to accomplish the apparent incompatibility of the two dichotomies. To improve the competitiveness of production in high-wage countries compared to production in low-cost countries, it is not sufficient to achieve a better position within one of the dichotomies; it is necessary to resolve the polylemma of production [SKBS07]. The research questions pursued within the Cluster of Excellence "Integrative Production Technology for High-Wage Countries" aims at dissolving this polylemma.

This research cluster unites more than twenty institutes and companies collaborating for this purpose. Professional competencies of the research partners are domain specific for certain aspects in production processes.

These companies and research institutions have implemented simulation applications, which diverge from each other with regard to the simulated production technique and the examined problem domain. One group simulates specific production techniques with exactness close to the real object. The other group that comprise a holistic production process do not achieve prediction accuracy comparable to the one of specialized applications. However, both types are state-of-the-art and commonly applied in university research. Furthermore most of the applied algorithms are not yet implemented in commercial tools. Hence, the simulation of a holistic production process is often not realizable due to insufficient prediction accuracy or the missing support of the regarded production techniques.

The combination of existing simulations covering and addressing specific aspects in process chains suggests creating a new and augmented comprehension of process chains as a whole. Using adequately simulated input parameters, which reflect the production history, to feed the next simulation in the chain, will most probably produce better results for that specific simulation than using standard assumptions or pre-computed values to parameterize the model. While the overhead for modelling and planning will be increased by simulating entirely interlinked processes, the expected results will be more accurate. Hence criterion for judging this highly planning oriented approach is the better value of the benefits in terms of insight, understanding, efficient technical processes, lower production costs or higher product quality without ignoring the costs of creating simulated process chains [CBKB08].

In solving the problem, it is necessary to interconnect different specialized simulation tools and to exchange the resulting data. However, the interconnection is often not achievable because of missing interoperability. To establish this interoperability of stand-alone simulations four levels of heterogeneity must be overcome. The first level comprises the technical heterogeneity. On this level, a communication infrastructure for data exchange has to be established. This problem is already solved by using middleware applications. On the second level, the syntactic heterogeneity is handled, which means that a common data format must be introduced with regard to information exchange. The third level addresses the semantic heterogeneity. The meaning of data and information has to be distributed, as an unambiguous definition of the information content is needed. The fourth level consists in the pragmatic heterogeneity. On this level, the differences between the used methods and procedures have to be compensated [LN07].

2 Related Work

In the field of simulations, the process development time using manually linked simulations incurs an overhead of 60 %, caused solely by the manual operation of the individual simulation components and conversion tools of a simulation chain [Lan03].

At the same time, integration problems belong to the most frequented topics with reference to finding answers to questions which are raised across application boundaries [HRO06, Whi05]. The complexity of such integration problems arises by reason of the many topics that have to be regarded to provide a solution. Besides application interconnection on the technical level, the data has to be propagated and consolidated. Furthermore, user interfaces are required to model the underlying process and a unified visualization of the data for the purpose of analysis. The necessary visualization depends on the requirements of the user and therefore has to consider the user's background. In addition, the integration of data requires the understanding and thus the comprehension of domain experts. Because of those reasons, integration solutions are often specialized and highly adapted to the specific field of application. One example for such a solution is the Cyber-Infrastructure for Integrated Computational Material Engineering (ICME) [Hau10] concerning the interconnection of MATLAB applications. Other examples are solutions that require making adjustments on the source level of the application, like CHEOPS [SYvWM04] or the FlowVR toolkit [AR06]. Yet others require the implementation of standards like SimVis [Kal07]. Realizing a flexible solution, the technical, the data and the analysis level have to be taken into account.

The interconnection on the technical level has been researched intensively. Several solutions have been presented during the last years [FK03, Hen08, Nat03]. In particular the use of middleware technologies has been established to provide a solution to such kind of problems. Middleware solutions used in the field of simulation interconnecting often require linking of hardware resources, in addition to the associating of the simulations. This issue is addressed in the field of grid computing. Popular grid middleware agents include Globus (www.globus.org) [Fos06], g-lite (glite.cern.ch), UNICORE (www.unicore.eu) [SRM10] and Condor (www.cs.wisc.edu/condor) [TTL08].

Concerning the data and information level, a conversion of the data syntax is not sufficient. Instead, the structure and the semantics of data have to be considered in the conversion process [Gag07, GSC95, SP91]. For such processes, the usage of schema- and ontology-based integration methods [ES07, RB01, SE05] has been established as a solution. Thereby, research mainly focuses on data schemas based on the relational or XML data model. In this respect, knowledge bases containing background knowledge about the application domain are often used to facilitate the semantic integration of data [Gag07, GSY06]. There are various research projects in this field which have produced different solutions for schema- and ontology-based integration, like COMA++ [ADMR05, EM07] and FOAM [Ehr05]. Both systems feature algorithms analyzing the structure of the schema and do not regard the stored dataset. Hence, these systems are unable to identify different dataset semantics within one schema.

3 Interoperability

The core objective is to achieve interoperability of the simulation tools without negating the autonomy of the individual applications. In this respect, autonomy means the degree to which the various applications can be developed and operated independently of one another [Blu06]. The development of standards and an application's need for implementation of such standards, in particular, constitute intervention in the autonomy of the individual applications. Often such intervention is not possible for technical, legal or competition-related reasons. Simulation tools developed within the field of production technology are characterised by different data formats, terminologies or definitions and the use of various models. The integration system developed creates a basis for overcoming the heterogeneity between the simulation tools, as mentioned in the introduction.

Figure 2 depicts that Integration, preparation and extraction are key functionalities for interoperability realization. Through integration, data provided by a simulation tool in one data format is transferred to the central data store of the integration system then, using extraction, this data is converted into the data formats of other simulation tools while the semantics of the data are retained. To this end, there is a data preparation step prior to the actual extraction in which the data provided is transformed using semantic transformations to make it suitable for extraction into

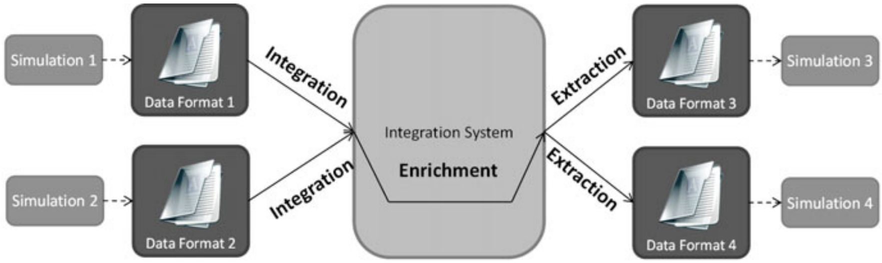

Fig. 2 Semantic interoperability between simulations

a specific data format. Hence, some material processing simulation tools require, for instance, specification of the outer surfaces of a component's geometry. This information, however, cannot be contained in the data captured. Within data preparation, these surfaces are automatically identified and enhanced in the data. Extraction takes this data into account and can therefore deliver a valid geometry description.

The basis for the integration system is the AdIIuS framework (Adaptive Information Integration using Services) developed in the Department for Information Management in Engineering at RWTH Aachen University, Germany [MMSJ10]. The AdlluS provides a basic framework for integration systems in which applications with complex data models and formats are integrated along a process allocated during run time. It was built in this Cluster of Excellence in order to facilitate the development and networking of other integration systems in the field of production technology. The framework is based on process-driven information and application integration. This means that each request is handled by means of a process of pre-defined work steps. In this respect, application integration involves tracking the provision of data for the simulation tool used in the next simulation process, while information integration entails integrating the data provided into the central data store of the information system. The integration system must first integrate the result data into the collected simulation process data and then provide the data for the next simulation in the simulation process. In so doing, it is essential to overcome the heterogeneity of the data formats and models of the simulation tools by applying transformations.

The integration stage of the process involves transferring the data from the data model of the data source into the central data model of the integration system, the "canonical data model" [Hoh02]. Given the volume of data and the complexity of the data structures, the canonical model used in the integration system is a relational database model. Besides the relational model, the AIIuS framework also supports other canonical data models. Hence the data can be deposited in the XML data model, for example. The integration process is based on the ETL process whereby first the data source is opened to allow the data to be extracted, then the data is transformed so that it can be loaded into the canonical data model. Data transformation to achieve the necessary syntactic and structural adaptation does not, in this case, produce any changes in the semantics of the data. Semantic transformation is not

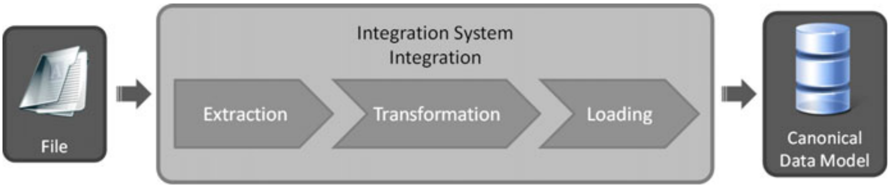

Fig. 3 Integration process

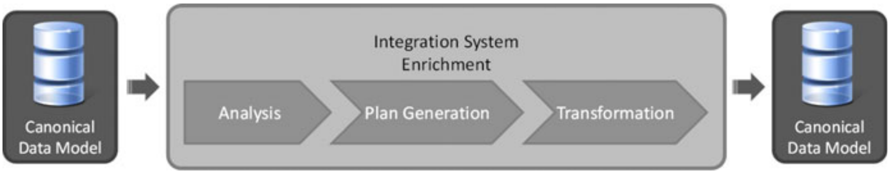

Fig. 4 Preparation process

executed until the data preparation stage. In order to distinguish between the different types of transformation, the transformations designed to overcome syntactic and structural heterogeneity will hereinafter be referred to as data transformations, while the transformations executed in the data preparation stage to overcome semantic heterogeneity will be referred to as semantic transformations.

Once the data has been integrated into the canonical data model, it can be prepared for extraction. Within the AIIuS framework, this is achieved through a combination of methods from semantic information integration and artificial intelligence planning. Data preparation results in transformed data with semantics that meet the requirements of the data format to be extracted. Data preparation also comprises enhancement with new information, e.g. the temperature profile in selected points.

Data preparation uses the structure and methods of schema integration. In this respect, the focus is on overcoming semantic heterogeneity. Generic schema integration processes, such as DELTA (Data Element Tool-based Analysis) [CHR97], DIKE (Database Intensional Knowledge Extractor) [PTU03, MBR01], which operate on the basis of the identifiers and the structure of the schema, may well provide an initial approach, but they are not sufficient for identifying the required semantic transformations of the data accumulated in the integration system. Likewise, instance-based processes like iMap [DLD+04], Automatch [BM06] and Clio [HHH+05], which are designed to identify correspondences using the datasets included, are also inadequate. This is because the actual transformation process depends not on the schema, but on a specific dataset and is only applicable for that dataset. In a first step, the preparation process analyses the data concerned according to the kind of attributes and identifies the requirements placed on the attributes by the target schema. In a second step, a plan is generated which contains the transformation process for preparing the data. The actual semantic transformation of the data takes place in the third step. Below is a description of the extraction process

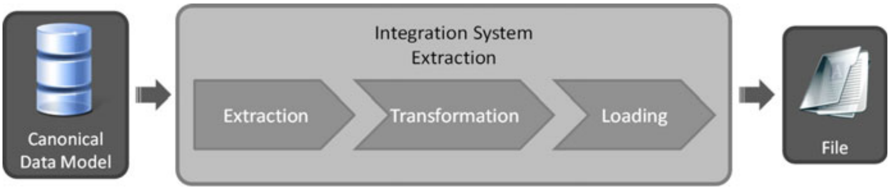

Fig. 5 Extraction process

which ensures that after it has been prepared, the data is transferred into the required data format and model.

During extraction, first the data is extracted from the data store. Its structure and syntax is then adapted via data transformations to match the required data format and model. Finally, the data is loaded into the specific physical file. Implementation of the processes requires certain functionalities, which are provided by corresponding services. The integration, preparation and extraction services are used to overcome the heterogeneity of the stand-alone simulations.

4 Use Case

The interconnection of simulations used in a production process of a gearwheel is considered for the validation of the simulation interoperability. The gearwheel is manufactured in several working steps (Fig. 6). Two levels of detail are examined in the manufacturing process of the gearwheel. The first level of detail is linked to macro-structure processes like forming, heat treatment and welding. The second level of detail is linked to the examination of the micro-structure. The micro-structure data is homogenized on a transfer level for the use on the macro-structure level.

For each used simulation along the production process interoperability must be granted. That means all used data of the five simulations must be represented by structure, meaning, value etc.

In the use case the blank will get a heat treatment as a preparation for the recast process, in order to use the best material data a microstructure analyses will be made after every macro-structure process step. With the results of the heat treatment we will find out the micro-structure data for a few representatives points of the blank. In order to use this information for the whole macro-structure a homogenization tool is used to step up the micro-structure data to the macro level. The results of the heat treatment and the micro-structure simulation are used as input for the following recast process. This procedure is repeated for the next heat treatment and the welding process [SGH08].

The framework gathers all parameters that are needed for a complete and automated run through the whole simulation chain. The framework will organize and

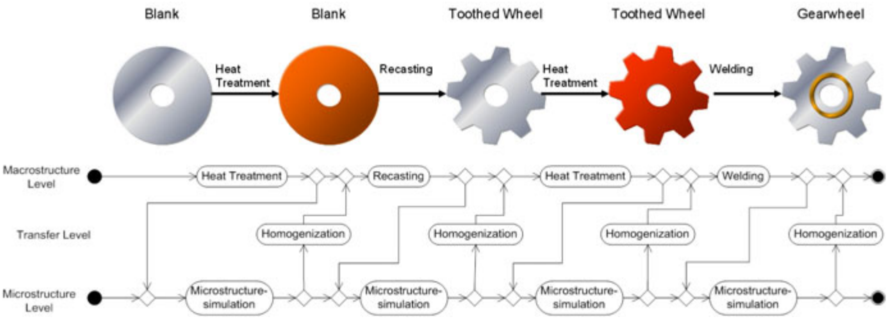

Fig. 6 Simulated gearwheel production process

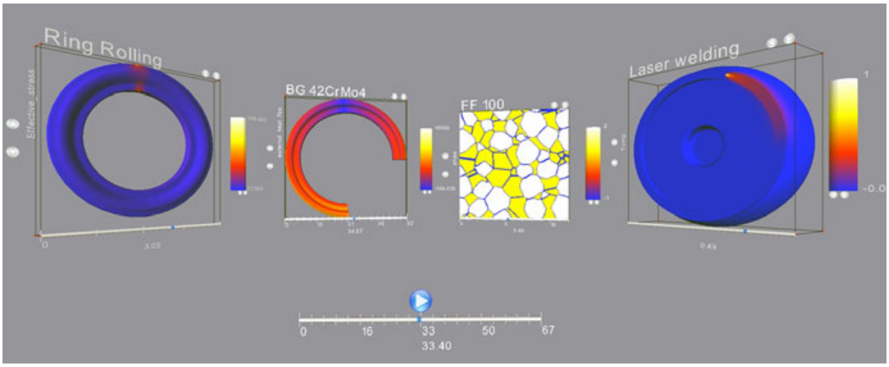

Fig. 7 Simulation results – gearwheel production process

administrate the order of the simulations to match the production process. Furthermore it will provide for each simulation the input data.

Via the components of the framework the syntactic and semantic simulation interconnection is realized. On the base of this interoperability all parameters and their values that are generated by the simulations are available for every downstream simulation in the chain. Thus, in any further process step which will be simulated the entire process history is accounted, this leads ultimately to a better data set for all simulations. Figure 7 shows the simulation results of the gearwheel production process.

5 Conclusion and Outlook

The Framework reads the input and output files of the previously mentioned simulations. Additional it understands and generates new files according to the schemes presented in Figs. 3, 4 and 5. Therefore, all parameters that cannot be generated by the process must be known in addition to the input file of the first simulation.

Integrating these inputs and results of a simulation process into a data model is the first step towards gaining insights from these databases and being able to extract hidden, valid and useful information. This information encompasses, for example, the quality of the results of a simulation process and, in more specific use cases, also the reasons why inconsistencies emerge. To identify such aspects, at present the analysts use the analysis methods integrated in the simulation tools. Implementation of the framework, however, opens up the possibility of unified consideration of all the data since it encompasses the study and analysis of the data generated along the entire simulation process. Various exploration processes can be called upon for this purpose. What needs investigating in this respect is the extent to which the information extracted through exploration processes can be evaluated. Furthermore, how this data can be visualised and how information, such as data correlations, can be adequately depicted should also be investigated. To this end, there are various feedback-supported techniques that experts can use via visualisation feedback interfaces to evaluate and optimise the analysis results.

The afore-mentioned data exploration and analysis may be further undertaken as follows: First, the data along the simulation process is integrated into a central data model and schema. Then, the data is analysed at analysis level by the user by means of visualisation. In so doing, the user is supported by interactive data exploration and analysis processes which can be directly controlled within the visualisation environment. Since it is possible to send feedback to the analysis component, the user has direct control over data exploration and can intervene in the analyses.

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