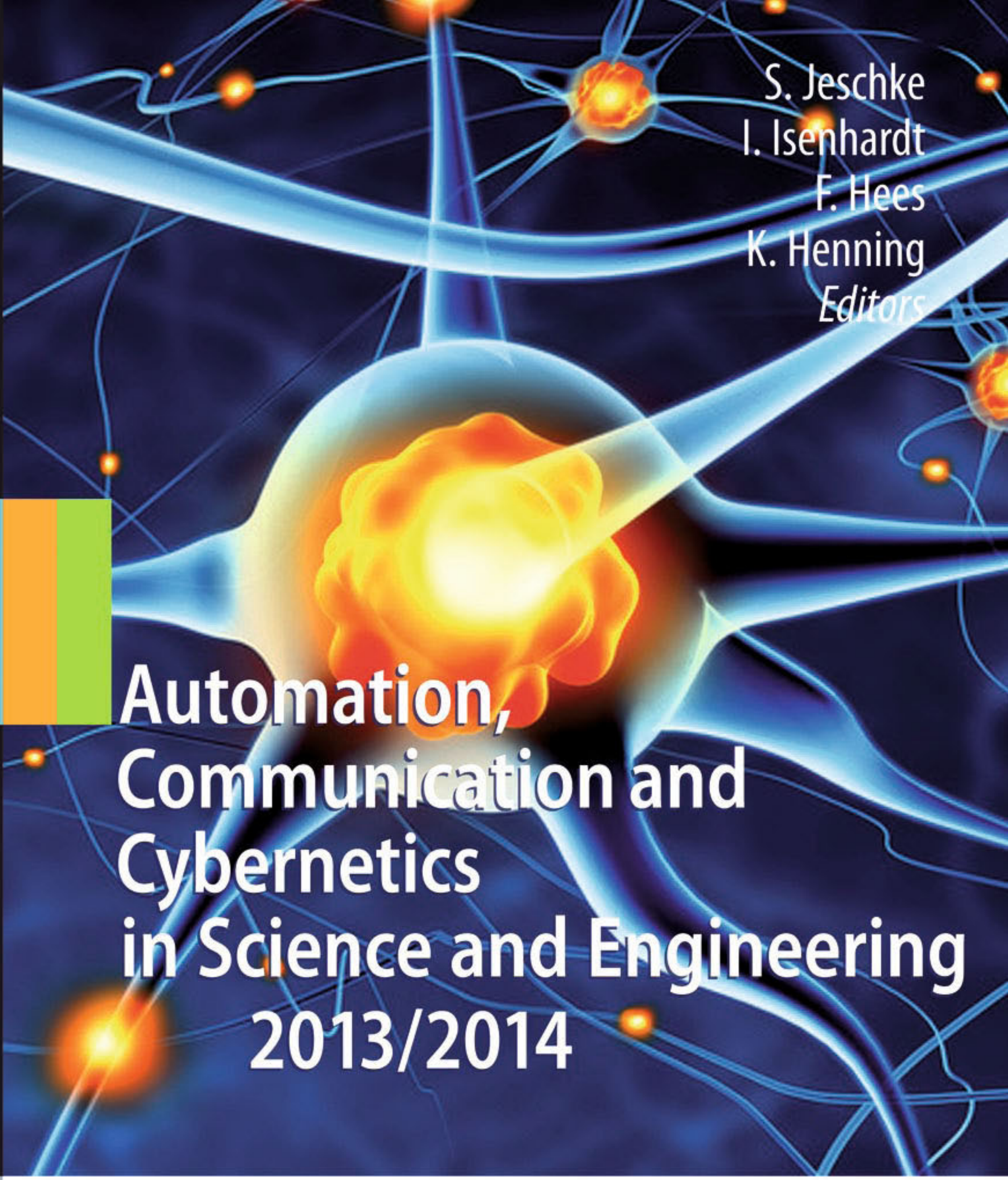

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*Editors*

# Automation, Communication and Cybernetics in Science and Engineering 2013/2014

RWTH AACHEN UNIVERSITY

IMA ZLW IfU

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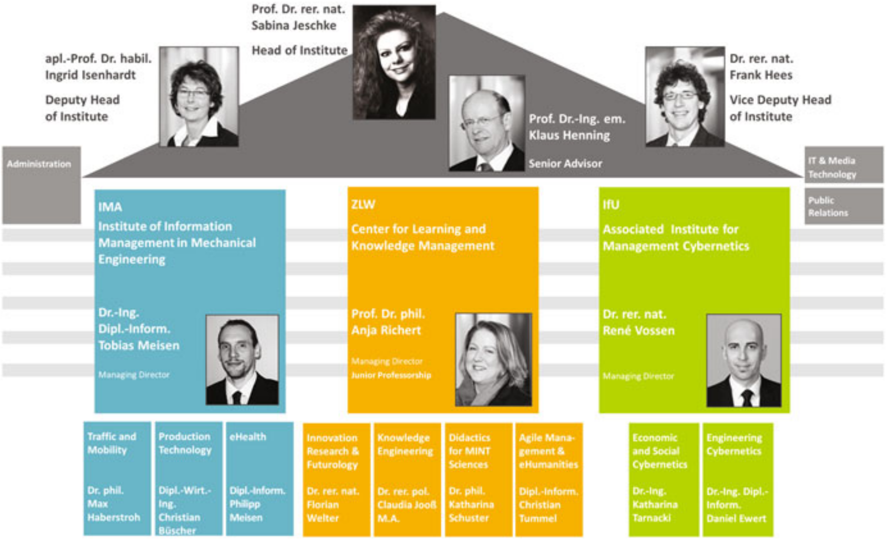
# Foreword

Dear Reader,

We are very proud to present to you the third instalment of our book series "Automation, Communication and Cybernetics". This series brings together our scientifically diverse and widespread publications from July 2012 to June 2014. Almost all publications are peer-reviewed and have been published in recognised journals, books or conference proceedings of the various disciplinary cultures. In the last edition we presented you the new organisational structure of our institute cluster IMA/ZLW & IfU. Below you can see an updated version, where the cluster is headed by the three directors with Sabina Jeschke as Head of Institute and Ingrid Isenhardt and Frank Hees as her Deputy and Vice Deputy. The former head Klaus Henning still provides us with advisory support. The cluster itself consists of three institutes; the **Institute of Information Management in Mechanical Engineering IMA**, the **Center for Learning and Knowledge Management ZLW** and the **Associated Institute for Management Cybernetics e.V. IfU**, which are managed by Tobias Meisen, Anja Richert und René Vossen respectively. Our research activities are arranged in nine different research groups whose activities are described further below.




Although the structure itself has not changed the people or their statuses have. Our Deputy Head Ingrid Isenhardt is now an adjunct professor at the Faculty of Mechanical Engineering at the RWTH Aachen University. With Tobias Meisen the IMA got a new Managing Director. He takes over from his predecessor Daniel Schilberg who has left us by now to become a full professor in Bochum. The IfU is now directed by René Vossen.

- Within the IMA there are three research group leaders: Max Haberstroh for the group **Traffic and Mobility**, Christian Büscher for **Production Technology** and Philipp Meisen for **eHealth**.
- In the ZLW Christian Tummel took over the research group **Agile Management & eHumanties** which replaced the former group of Career Research. Claudia Jooß heads the group **Knowledge Engineering**, Katharina Schuster the group **Didactics for MINT Sciences** and Florian Welter the team **Innovation & Research Futurology**.
- At the IfU the heads of the research groups are now Katharina Tarnacki and Daniel Ewert for the groups **Economic and Social Cybernetics** and **Engineering and Cybernetics** respectively.

With 80 % of our research group leaders now being PostDocs our reorganisation proved to be very successful since this was one of the main motivations for the restructuration. Below we will give a more detailed description of our research activities in the individual research groups.

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

- The scope of the research group **Production Technology** is to provide innovative research regarding information management in virtual production and production.

The group is specialised in methods and procedures to integrate, to consolidate and to propagate data generated in these domains. In addition, their research focuses on visualisation and interaction techniques to enable the user to analyse the retrieved information in an explorative and interactive way. Thereby, their research covers a broad range of different areas especially virtual and automated production. Meeting the challenges of information management within these areas, the group studies information integration, descriptive and predictive analysis using a variety of techniques from artificial intelligence like regression, machine learning, natural language processing and data mining as well as interactive and explorative visualisations. Regarding the domain of virtual production, the group has shaped the concept of the Virtual Production Intelligence to collaboratively and holistically support product-, factory- and machine planners. The work of the group provides essential basics to facilitate the realisation of cyber-physical production systems and therefore is a cornerstone of information management in Industry 4.0.

- The research group **Traffic and Mobility** is working on concepts for multimodal freight transport and urban mobility, intelligent transport systems and on the design of user-friendly and barrier-free mobility solutions and human-machine-interaction. In its projects, the research group investigates concepts for autonomous vehicles, advanced driver assistant systems and the interactions and interdependencies between humans, organisation and technology. In order to develop holistic solutions, the interdisciplinary team combines skills and knowledge from engineering, computer science, sociology and economics. The applied methods of the research group range from simulator and real-life testing, over usage-centered design, empirical studies and acceptance or mental stress and strain analysis. One approach to reach the ideal of efficient freight traffic of the future is to use modular, worldwide usable loading units with appropriate transport carriers. All research is based upon the holistic consideration of the three recursion dimensions: human, organisation 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** focuses on research considering information management supporting healthcare. The group is specialised to meet the challenges within the research fields predictive data analytics and visual analytics. The research group understands itself as an "integrator" within the eHealth domain: educating and providing experts in the mentioned research fields, but also understanding the importance of covering and dealing with problems of all phases (i. e. needs assessment, integration, evaluation, and deployment) of the information management cycle. Lately, the group focused on research topics occurring in scenarios of medical emergencies, thus developing an intelligent and reliable ad-hoc network structure streaming medical data in real-time from the case of incident to an expert. Predictive analytics is used to detect upcoming delays, future connection losses, or approaching quality reductions. The eHealth group coined the term "prescient profiling" which is used to describe an AI driven concept selecting

relevant laypersons to nearby medical emergencies. To determine relevancy the solution considers for example traveling speed, known behavioural patterns (i. e. trajectories), current circumstances, and infrastructural limitations. Currently, the group works on an algorithm to predict the emotions of a driver interacting with a navigation system to adapt the systems behaviour accordingly. In the near future, the group will also use its expertise to establish a complex and highly available information management system for rapidly changing ad-hoc infrastructures that are for example needed to ensure information availability in the case of major incidents.

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

- The research group **Innovation Research and Futurology** focuses on two fields. Innovation research concentrates on a concept of innovation management, which not only comprises planning, realisation, and design of processes and structures to create innovation, but also stresses the innovative capability. The first research field focuses on innovation systems with various dimensions like regional and national innovation systems as well as their relevant subsystems, which are created and analysed from a cybernetic perspective. This is achieved by a holistic consideration of the system-intrinsic dimensions "human, organisation and technology", in order to produce innovative capability of the involved actors under competitive and sustainable conditions. The second field of the research group depicts futurology. Here, a monitoring approach is applied for different research, development and funding programs. Consequently, a range of future trends, scenarios and development strategies is derived for respective target groups. This expertise is supplied to experts in science, economy and policy.
- The research group **Knowledge Engineering** comprises engineers, human and cultural scientists, social scientists, economists, geographers, and computer scientists who work in the field of cooperation research. Together, they examine which structures and processes need to be modeled and implemented in order to capture, support and develop communication and cooperation. The research currently focuses whether and why the knowledge production can be promoted within inter- and transdisciplinary research alliances e. g. the Clusters of Excellence. Thus, the research group advocates a knowledge engineering approach addressing the interaction between data, information, and knowledge on all organisational levels. It then leads to services and products that iteratively and cooperatively integrate customers and users into the solution process. Current fields of action deal with the management and governance of research alliances, the diversity management in innovation processes and the organisation of work, the measurement of performance as well as the intellectual capital. Another focus is put on the technical aspects of knowledge management, such as the semantic search and the design of (multimedia) learning environments. Furthermore, the research group conducts consulting, moderating and coaching activities for the organisational and strategy development as well as the cooperation design and knowledge management.

- With an interdisciplinary team of communication scientists, engineers, psychologists, sociologists and computer scientists 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 students, teaching staff, intermediate organisations and other experts on university didactics, are integrated in our research activities. The user oriented approach of the research focuses on learning in virtual environments, learning with natural user interfaces and VR-technology, remote and virtual laboratories and other forms of computer and web based learning. Moreover, social aspects of learning in a higher education context are investigated. Here, the focus lies on mentoring concepts, students' mobility and service based learning methods. In all its activities, the research group considers the whole student life cycle, from pupils, bachelor- and master students up to doctoral candidates.
- The research group **Agile Management & eHumanities** deals with the application of Big Data Technologies in social sciences and humanities. The major effort is the use of computer-assisted processes and the systematic use of digital resources in these disciplines. The main emphasis is set on the field of Big Data Analytics in the context of social media. In order to manage continuously increasing complexity and dynamic in organisational structures the field of Agile Management investigates the application and the implementation of agile methods, techniques, principles and values. In the application area of the research on competencies, one the focus lies on the analysis of the "digital footprints" from employers and staff, which allows drawing conclusions on hidden profile characteristics ("Recruiting 4.0"). The identification of these hidden characteristics and their significance for tomorrow's job market are up to date research topics in this field.

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 industrial applications. The main research topics include the assessment of organisational culture and structure, business model innovation and development of decision support tools. In the context of evaluation and decision support enhanced economic assessment tools including uncertainty and soft aspects and sustainability assessment tools are generated. In interdisciplinary research projects cybernetic tools and solutions for complex problems in collaboration with industrial and research partners are developed. The employed methods include system dynamics, viable system model, organizational culture assessment instrument (OCAI) and business model canvas. Furthermore, cybernetic tools for the development of sustainable product strategies, design of efficient organisational structure, culture based implementation of quality management, and change processes are applied.

- The research team **Technical Cybernetics** is a part of the Institute for Management Cybernetics at the RWTH Aachen University. Its research objectives are intelligent planning and control algorithms for technical systems. The focus is on mobile robotics within intralogistic applications as well as process planning and industrial robotics. Here the group addresses aspects of human robot interaction and collaboration. The main goal is to endow the respective technical systems with autonomy and situational awareness in order to achieve more robust behaviour and an increased flexibility while at the same time simplifying the interaction with those systems. (Multi-) agent technologies, closed loop control systems and visual servoing, and natural interface technologies play an important role. The research group also maintains the institute's school labs.

Our deepest thanks go to our scientific staff that with their enthusiasm, interdisciplinary skills and capability to think outside of the box, push the institutes' research forward. We also would like to thank our support teams from administration and technology who always have our back in our daily drudgery with forms, regulations and IT-troubles.

Aachen, September 2014

Sabina Jeschke
Ingrid Isenhardt
Frank Hees
Klaus Henning

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

# Brisker Do Research – Two Strategies for Improving Innovation

**Ursula Bach**

**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 governance and network management to support the policy about "Occupational Health and Safety". 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.

**Keywords** Occupational Health and Safety · Network Management · Transfer 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 integration of partners within research groups" and "avoidance of 'fragmenting' of a research community", the founding priority Preventive Occupational Health and

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Safety applied different network management methods [1]. 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 [2], 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 [3]. 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 [4]. Here, all design components are verified regarding their relevance for Preventive Occupational Health and Safety and adjusted where necessary. As the individual design components


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

are heavily cross-linked, an adequate complexity dimensioning of the components among themselves must be achieved [5]. 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 [6].

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

1. b) 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 [7].
2. b) 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).
3. b) 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".
4. b) 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 [9]. 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 [10].

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. [8], 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 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 [11]). Within the third phase, research networks with private

**Table 1** Own compilation of the phases and their requirements for a network management of the funding priority according to Ahrens D. et al. [8]

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

and/or public funding have to pay special attention to later utilization of their projects' results [12]. Leisten further suggests keeping appropriability in view across all of the research process [13]. 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. 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

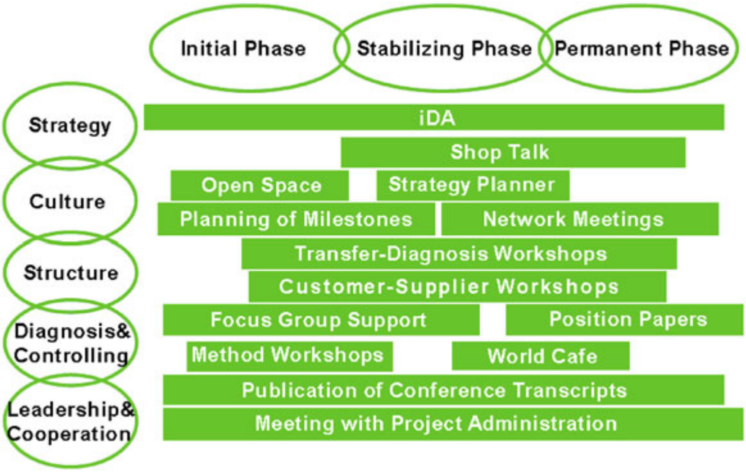


**Fig. 2** A variety of possible management methods and network services within the funding priority with consideration to the phases and design elements

and experiences as well as new contacts to the Preventive Occupational Health and Safety community [11]. 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 [11]. 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" (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 [14].

### *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

| | | |
|---|---|---|
| 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 |

**Fig. 3** Exemplary set of qualitative criteria for successful network management

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" [15] must be factored in, like e. g.

- Formation of a joint identity,
- Strengthening of a shared research interest [16],
- Building of mutual trust between individual members of the funding priority [31] and
- A common language of the funding priority [17].

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 Fig. 3).

## 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 de-localization 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 [18].

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 [19]. 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”? [1] 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 [1] but also [20]). According to [21], 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. [1] 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 [14].

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 [19]. "The problem of knowledge transfer already begins during the phase of knowledge generation" [22]. 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 [23]: 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 [14].

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 [24]. According to Scholl [25], 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 [26]. 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 [27], 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" [28] (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 [27] 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. The more intensive the interaction and requirements on cooperation between research and practice become, the better foundations are created for adopting mutual perspectives and the conjoint creation of knowledge.

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 [1]. 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 [29] 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 [30]. 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" [28] (own translation).

## 5 Conclusion

The integration of the two approaches "Strategic Network Management to support Preventive Occupational Health and Safety" 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.

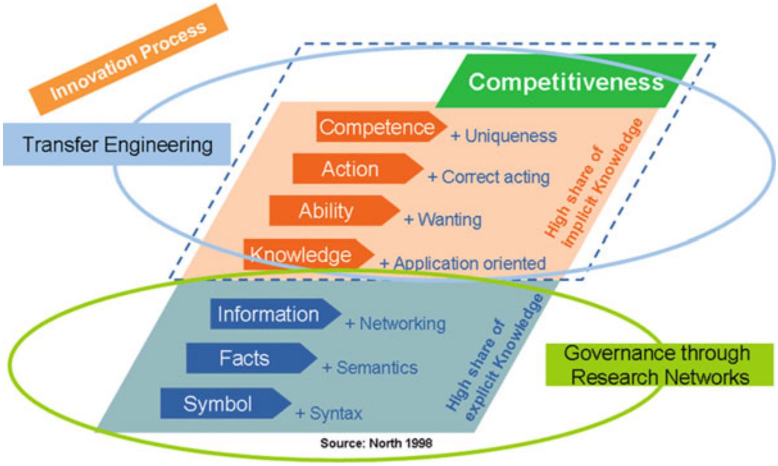


**Fig. 4** Innovation Process and Governance through Research Networks

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 and strengthens the innovation process (cf. Fig. 4).

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# The Telemedical Rescue Assistance System "TemRas" – Development, First Results and Impact

**Christian Büscher, Jesko Elsner, Marie-Thérèse Schneiders, Sebastian Thelen, Tadeusz Brodziak, Peter Seidenberg, Daniel Schilberg, Michael Tobias and Sabina Jeschke**

**Abstract** German emergency medical services (EMS) face the challenge to ensure high-quality emergency care against a background of continuously increasing numbers of emergency missions, resource shortages concomitant with greatly increased arrival times, particularly in rural areas. Because German EMS physicians are at maximum capacity, an immediate response is not always possible and thus delays in commencing advanced life support measures sometimes occur. In such scenarios, paramedics start the initial treatment until the EMS physician arrives. The delayed availability of a physician can defer the decision process of the paramedics and thus postpone the start of the patient's essential treatment, which is particularly dangerous during the care of cardiovascular emergencies. Therefore, the project TemRas (Telemedical Rescue Assistance System) has developed an innovative concept to improve quality of emergency care. The objective is to introduce so-called tele-EMS physicians providing remote medical support for the emergency team on site by transmitting audio and video data, as well as vital signs and 12-lead-ECG from the emergency site to a teleconsultation center. In this paper the development process as well as first results of the evaluation phase and the impact for further use of telemedicine in emergency medical services are presented.

**Keywords** Emergency Medical Services · Healthcare · Teleconsultation · Telemedicine · Quality Assurance

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## 1 Introduction

With more than 30 % of today's emergencies having a cardiovascular background, response and arrival times of emergency medical services (EMS) are of crucial importance [1]. To ensure a sustainable medical treatment and increase survival rates, diagnosis and treatment have to be done as soon as possible. However, the increasing numbers of emergencies combined with a shortage of so-called EMS physicians result in an opposite effect; the untreated time interval in an ongoing emergency gets longer [2]. The German EMS rendezvous system consists of paramedics and separately disposed EMS physicians to perform the medical treatment. Within this premise, telemedicine and the use of telemedical emergency systems is gaining importance [3–6].

This challenge is the focus of the research project Telemedical Rescue Assistance System (TemRas), which aims to support the EMS team on site with a so-called tele-EMS physician. A complex IT system is developed and implemented that allows real-time data streaming from the case of incident to a teleconsultation center; these data included vital parameters, pictures, video streaming, and voice data. Specially trained physicians are connected to the system from this remote center and can therefore analyze and interpret the streamed data and communicate with the EMS team on scene.

The predecessor of this project called "Med-on-@ix" [funded by the German Federal Ministry of Economics and Technology (BMWi) from 2007 to 2010] prove the actual plausibility of such a system by equipping a regional ambulance with an early prototype of this system. The "TemRas" project focuses on real-life conditions and on improving the prototype toward a marketable product that comprises adaption of the hardware and software as well as the organizational concept [7]. In total, six ambulances have been equipped with the new hardware and communication devices to run a significant case study. The complete bundle of the IT system, combined with modern training concepts and a user-centered system design, is an essential step for the future rollout of the concept.

This article offers an insight into the design and implementation strategy pursued in the project TemRas as well as its first results and impact for further use of telemedicine in EMS. The project description is followed by pointing out the implementation process and the resulting technical system. In addition, the overall medical-organizational concept and first technical and medical results of the evaluation of TemRas are presented. The article concludes with a discussion of the sustainability and the benefit of the project results reached so far according to usage of telemedicine in EMS and its resulting quality improvement of emergency care.

### 1.1 *The Project "TemRas"*

The TemRas project constitutes the consequent continuation within the research field Telemedical Rescue Assistance System (TRAS), which evolved with the predecessor project "Med-on-@ix" and has been developed by partners of industry and the RWTH Aachen university as well as the University Hospital Aachen. The research activities within the consortium follow the common goals of increasing quality of EMS and greatly enhancing the involved processes by optimizing information flow with state-of-theart communication technologies. Although "Med-on-@ix" pursued the objective to give proof of the general concept of a TRAS by equipping a single ambulance with a system prototype [8, 9], TemRas represents the consequent continuation of the development to provide a market ready product. To position Aachen as the model region of a successfully implemented TRAS, the research strategy focused on two main goals [7]:

- The original system prototype is enhanced by integrating new heterogeneous components to enable optimized detection and therapy in case of cardiovascular emergencies.
- A detailed concept for launching the system into the market is developed.

The central development task of the consortium is the miniaturization and consolidation of the necessary subsystems, which have been originally developed and tested during the predecessor project and needed to be updated, and optimized to fulfill the needs for a real-life system launch. The main objectives are, e. g., the ergonomic design of the system components to increase acceptance and ease of use as well as the integration of new components (e. g., different producers) for enhanced flexibility and extensibility referring to the results of user surveys conducted to evaluate the first prototype [10].

Aside from a possible increase in the quality of service itself, economic feasibility studies have shown that a cost-effective implementation can be achieved by a broader system implementation and its corresponding economic scale effects [11]. Therefore, the system is implemented in six ambulances in the region of Aachen (Germany) and neighboring communities that are connected to the teleconsultation center, generating important data within a 1-year evaluation period to assure the usefulness under free market conditions in urban and rural areas.

Since 2012, this evaluation phase is running. It has to be stressed that these ambulances are fully integrated into the regional emergency workflow and therefore generate valuable data representing a case study under real-life conditions. Paramedics on scene can now officially consult the connected tele-EMS physicians and use the offered services to get remotely accessible medical expertise to ensure fast treatment of high quality. Evaluating the early gathered data and accessible information generated within the first months of usage (174 successful teleconsultations have been performed up to the end of 2012), the increase in efficiency and general impact appears to be a very promising approach in enhancing the quality of service within EMS.

Analyzing international EMS and therein existent telemedical projects with similar basic approaches, other research projects have focused mainly on the technical feasibility of prehospital, mobile telemedicine [4, 5, 12, 13]. Current research literature, to our knowledge, does not present projects that accompany the integration of such telemedicine systems into EMS with scientific evaluation of medical impact, organizational consequences, and technical challenges. Comparable integrated systems are the DREAMS Telemedicine System from the USA [14] and the Viewcare Telemedicine System from Denmark [15], but neither of these are covered by published research literature. After several expert interviews and own experiences gathered in the past few years, the TemRas system was initiated to have huge impact on the service quality and the cost effectiveness of future EMS worldwide.

## 2 Materials and Methods

### *2.1 Development Process*

In August 2010, researchers and developers began to develop the concept of the optimized TRAS. The technical improvement took place mainly within the first 2 years of the project. During this phase, the involved physicians, engineers, and sociologists worked closely together in a highly interdisciplinary team to identify and take into consideration all the relevant aspects of the new system [16]. The system's design was created in a mainly linear process with strong user participation and close feedback loops between engineers and users. The original intent of a true iterative, agile development process could not be realized for the whole system but was instead used to develop the individual user facing software components [17].

Furthermore, in 2010, five emergency districts were chosen for the evaluation of the newly developed system and the criterion for choosing the districts was mainly the structural condition (number of emergencies, density of supply and network coverage).

In 2011, the focus of the project work was primarily the restructuring of the teleconsultation center, the redevelopment of the miniaturized communication unit (peeqBOX), equipping the corresponding ambulances with the necessary technical devices, and the development of an integrated system. During the transition in 2012, the TRAS was subjected to intensive testing and the involved paramedics were trained. Physicians were prepared during special training events for their future role as tele-EMS physician within the TemRas system to prepare for the study. Since August 2012, the running system is scientifically evaluated in its planned configuration of six ambulances and two tele-EMS physician workplaces under real-market conditions, fully integrated into emergency workflow of the involved cities and districts. The overall development process is shown in Fig. 1.

Major software updates, working place restructuring, enhancement of the ergonomic design, and process optimization combined with a detailed workflow analysis were implemented to fulfill the new system requirements. Another focus


**Fig. 1** Development process of TemRas

was the telemedical integration of clinical establishments into the TemRas system to enable an instant information flow and register the incoming patient for continuous treatment, e. g., cardiac catheterization, intensive care, trauma room.

Aside from adjustments in the conceptual alignment, close cooperation with the health insurance companies were strived to bring forward the economically efficient launch of the system; reducing the number of unnecessary hospital admissions and unnecessary march-outs of EMS physicians hereby prove well to have a strong basis for further negotiations. The hybrid combination of services – all around the technical implementation, the system maintenance, and the daily operation of the TRAS – and highly innovative medical useful products form the essential step toward market maturity of the telemedical system.

## *2.2 The Technical System*

The technical system integrates heterogeneous components and consists primarily of four subsystems: teleconsultation center, ambulance, on-scene equipment, and IT infrastructure (Fig. 2). A redundant and wire-tapping proof network guarantees the safe and reliable mobile transfer of patient data between the IT components and certified medical products on scene and between the ambulances and the teleconsultation center, enabling the telemedical support of EMS teams in emergency situations. The utilized medical products such as the ECG/AED (electrocardiogram/automated external defibrillator) unit and vital data display as well as a Bluetooth stethoscope are certified with the necessary medical certificates for emergency rescue environment.

The integration of the medical products is realized using the corresponding software and advanced programming interfaces, which are provided by the producers. A very important focus of the technical system lies within the concept of modularity [16]. The network that is part of the system consists of the communication units used within the project and the necessary software applications. This enables the system to

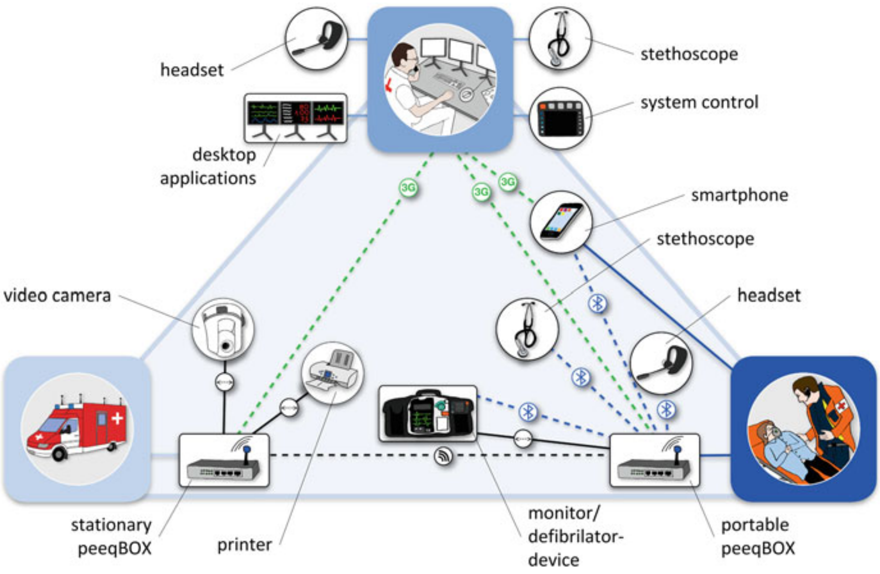


**Fig. 2** View on the technical components of TemRas [16]

be used in the mobile context of an emergency rescue environment. The independencies among all offered functionalities, which enhance the consultation, guarantee the exchangeability of individual components and units and therefore underline the sustainability of the concept. The working places within the teleconsultation center are connected to the server environment with a standard network cable connection. The telemedical connection of the emergency scene is realized using redundant mobile connections, either directly through the portable communication unit (peeqBOX) or via the mounted communication unit inside the ambulance. All occurring mobile data traffic is encrypted. The communication between portable peeqBOX and the peeqBOX that is mounted inside the ambulance car is implemented using a secure wireless LAN (WLAN).

### 2.2.1 Teleconsultation Center

The physicians working in the teleconsultation center (Fig. 3) are experienced, specially trained EMS physicians. *Via* mobile real-time connection, one of these tele-EMS physicians is continuously connected to the scene of incident. Data are transferred in real time to the tele-EMS physician to provide him or her with newest information on the ongoing case. This data flow enables the tele-EMS physicians to use their expertise and decide on possible treatment and order measures to be done by the paramedics on scene. Standard operation procedures (SOPs) and a specially developed documentation software support the tele-EMS physicians in implementing a guideline-fulfilling medical care toward the patients [18]. The availability of

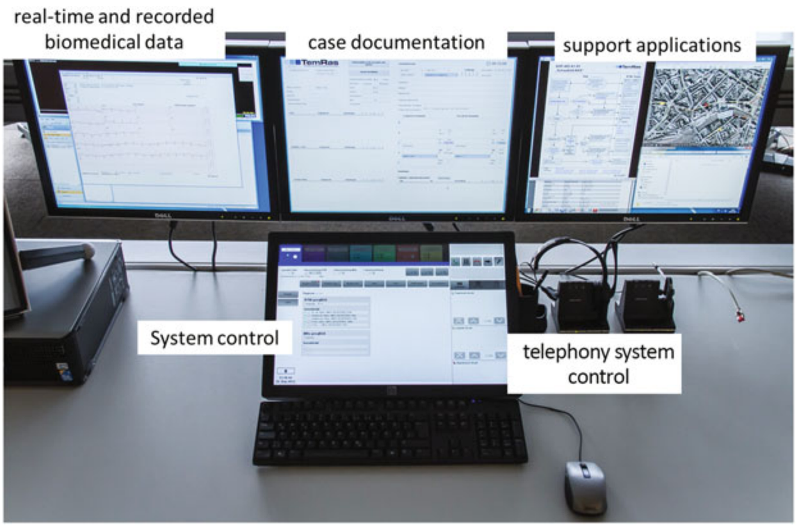


**Fig. 3** Tele-EMS-physician workplace

and therefore active orientation on up-to-date and qualified guidelines regarding the workflow within an ongoing medical emergency ensure a high-quality medical consultation for both the patient and the EMS team. Another new feature is the possibility to consult external information sources, e. g., during a rare disease. Aside from the option to directly contact the poisoning hotline, all tele-EMS physicians have access to external databases to support them in their diagnoses. Furthermore, other connections are available within the system, like for instance, experts in specific medical domains and reference persons within hospitals and other medical institutions.

### 2.2.2 On-Scene Equipment

The EMS teams on scene are using the portable peeqBOX, which has an increased functionality and has its original weight reduced from 10 to 1.8 kg (Fig. 4). This communication unit is responsible for establishing the connection to the teleconsultation center and is physically located in the side pocket of the ECG/AED unit. Using multiple bundled mobile network channels, a reliable data connectivity is provided to assure a potent data streaming from the case of incident to the tele-EMS physician. The paramedics on scene can easily connect to the teleconsultation center; the connection will be established using the best available network at the moment. The center can also be reached by calling special telephone numbers from a smartphone or a fixed phone, e. g., from inside a patient's apartment and are still integrated into the system.

The ECG/AED unit continuously collects vital data such as heart rhythm, blood pressure, and pulsoxymetry of the patient and transfers these data plus a possible

**Fig. 4** Miniaturization of the portable peeqBOX

12-channel ECG in real time to the tele-EMS physician for diagnose purposes. For auscultation, an electronic stethoscope is used. The integration of this stethoscope enables the transfer of hearth tones real time from the scene to the corresponding stethoscope of the tele-EMS physician. To provide as many information as soon as possible, the paramedics have the option to take photos and send them instantly to the teleconsultation center; lists of drugs and medical diagnoses and letters already available from the patient are two examples where a picture is very useful. The pictures are being sent automatically without any special action required by the person making them.

### 2.2.3 Ambulance

In addition, the tele-EMS physician can also accompany the patient on the way to the hospital or any other medical institution. Aside from the portable communication unit, every ambulance is equipped with a similar communication unit as fixed mounted version. With special antennas located on the roof of the car and additional data cards available, the stationary peeqBOX has an increased performance. For exchanging data with the portable peeqBOX, a secured WLAN is available, whereas all other components inside the ambulance are connected with a standard cable network. On the inside roof of each equipped ambulance, a high-resolution video camera is attached, which can be controlled remotely by the tele-EMS physician; the usage is bound to the agreement of an individual patient and is only considered if medically relevant. Generated video data is not stored in any way but instead consists only of the streamed data that is sent from the ambulance to the teleconsultation center. In addition, the printer inside the ambulance can be used to print the documentation protocol and be handed to a physician on scene or to any physician involved in further treatment – e. g., as first written documentation for patients who get assigned to an emergency hospital. This simple but effective feature can greatly enhance the information flow from EMS to the medical institutions.

The actual innovation of the described TRAS is determined by its mobility and modularity [16]. Compared with similar projects, TemRas also facilitates the option for telemedical consultations outside of the ambulance car, e. g., a patient's apartment or any kind of scenario inside a building. This is achieved by integrating the described variety of functionalities into one modular system architecture. The operation of the TemRas system is, with regard to up-to-date Medical Devices Act, without legal restrictions and is legally allowed to be implemented as a real-market system to enhance EMS in Germany [19].

## 2.3 *The Medical-Organizational Concept*

The actual communication between the paramedics and the tele-EMS physicians is paramount in the concept of TemRas. This communication is started by the paramedic on scene on demand and initiated with a simple button press on his or her headset. All involved user groups have been schooled and trained regarding the use of the system. The system supports the usage with and without an additional EMS physician on scene. When the physician is not (yet) on scene, measures can be ordered by the tele-EMS physician, which are then delegated to the corresponding paramedic. In the concrete case of an ordered measure, it is still in the paramedics' obligation to verify the measure for plausibility, but the final responsibility for this measure will be on the tele-EMS physician. The classical case in emergencies where the final responsibility is unsure is not the case within a TemRas system scenario. Therefore, paramedics gain legal security, which is another motivating argument for the actual use of the system [19]. Operation possibilities for the paramedics are therefore enhanced, which can result in a decrease in the untreated time interval for patients. Furthermore, medical measures can now be analyzed and the effects be monitored in real time, which can greatly enhance the handling possible complications. Even after an additional physician arrived on scene, he or she can be supported by the connected tele-EMS physician (second opinion, ECG interpretation, assignment to medical institutions). The intended procedures have all been verified by legal opinions [19] and been approved by the Ethics Committee of the University Hospital of Aachen (EK 191/11).

To structure and optimize all processes in combination with the usage of the system – especially for the medical treatment of patients – so-called SOPs have been developed (Fig. 5). The medical SOPs provide an algorithm- based and guideline-corresponding medical care of the patient, which is already an established feature of clinics [18]. For the work of the tele-EMS physician and the EMS team on scene, SOPs for the most common emergency situations have been developed based on national and international guidelines. The tele-EMS physician can access these SOPs any time interactively. For the discussed emergency situations, these SOPs prove to be a valid base of up-to-date and guideline-fulfilling processes for diagnoses and treatment with additional information. SOPs therefore effectively support the tele-EMS physician and the paramedics on scene in the process of decision making, which can increase the general quality of service.

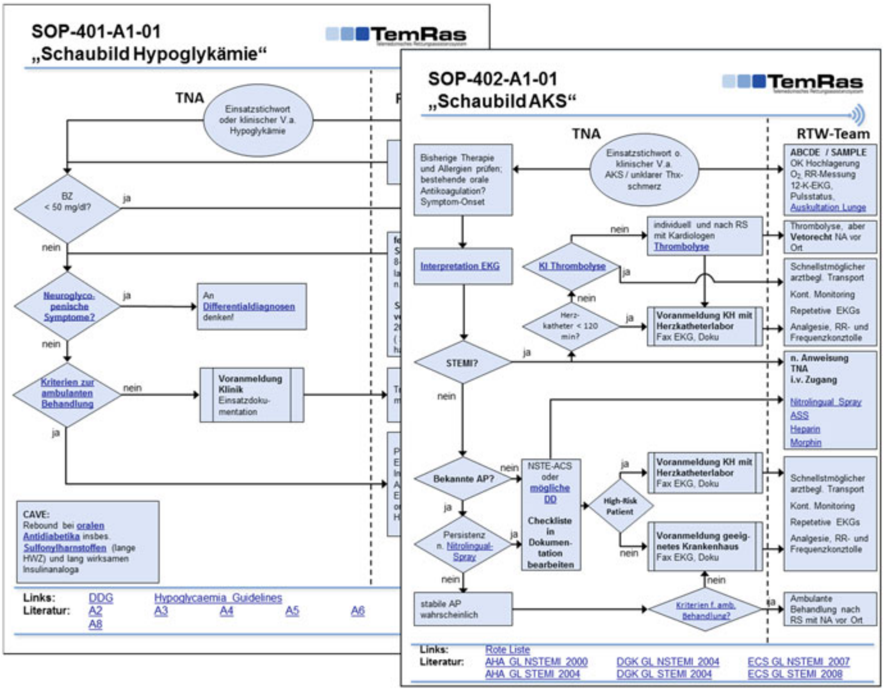


**Fig. 5** Examples of SOPs

# 3 Results

Since August 2012, the system is being evaluated in a real-life environment in the planned configuration of six ambulances and two tele-EMS physician working places. Seventy consultations have been successfully processed using the TemRas system in the first 10 weeks. The following section will show the results gathered within this period of the system in a real-life environment and will also discuss shortly the tests that were made in advance [20, 21]. A detailed presentation and discussion of all evaluation results will be performed after the evaluation phase.

Although the described technical system is currently at its development stage, it is suitable for use in a real-life telemedical consultation environment and is therefore already integrated into the EMS workflow in the discussed areas. During the testing period and before the actual evaluation phase, several unit, system, and performance tests were executed. An *ex ante* evaluation of a precise test is presented in the following. These tests were performed with a minimum of two and a maximum of four UMTS mobile connections accessible at a time (for comparison, in the productive system, a minimum of three and a maximum of five UMTS mobile connections are used). The real-time vital data transfer, which consists of curves and numerical values, had mostly good transfer results if at least one UMTS network was available.

As possible backup for non-optimal network connectivity (GSM, GPRS), the system offers the possibility to transfer data in periodic time intervals rather than continuously. During this periodic vital data transfer, all numeric values, events, ECG, and 12-channel ECG data are transferred every 60 s.

Connectivity from the EMS team to the tele-EMS physician is generally initiated on demand with the paramedic pressing the button on his or her headset. In average, it took $< 8$ s until the conference call had been established and up to 18 s until the tele-EMS physician was able to accept the incoming call [21]; the general target for the tele-EMS physician was to accept the call as soon as possible ($n = 5$). Photos on scene can be taken with a provided smartphone, whereas new photos are immediately forwarded to the peeqBOX via Bluetooth and then sent to the teleconsultation center using the available mobile network connectivity. The measured time intervals for transferring new photos ($n = 10$; 1 MP) from the smartphone to the peeqBOX (Bluetooth only) were about 30 s and 1 min for the complete transfer [21]. Video streaming was realized with a highresolution video camera attached to the roof inside the ambulance. With at least one UMTS network available, the streaming went without noticeable interruptions. As part of the ongoing case management, it is possible to switch between any available ambulances with the touchscreen application at the tele-EMS physician workplace. After switching from one ambulance to another, it took $< 8$ s until the real-time streaming of vital data resumed for the new ambulance [21].

The results show that with at least one reliable mobile connection available, an efficient teleconsultation can be conducted. The bad network coverage in some rural areas is at this point of development the most limiting factor, whereas teleconsultations in these areas are still possible due to the availability of the described backup solutions. Future development will focus on enhancing system performance in regions with bad or insufficient network coverage.

Seventy medical consultations – spread over different participating regions – have taken place within the evaluation period in the first 10 weeks. All these consultations were initiated by the paramedic on scene. Those 70 consultations are divided into 63 primary consultations and 7 secondary transfers. A primary consultation is the standard case, where paramedics on the scene of an emergency call the tele-EMS physician, whereas a secondary transfer is a well-planned relocation of a patient into another medical facility [22]. The daily system checks, which also test connectivity and therefore connect the EMS team to the teleconsultation center, are not counted as consultations. Taking a closer look at the operating times of the primary consultations, the average consultation length was in average 25.4 min (mean 25.4 min), with a standard deviation of $\pm$ 9.6 min. The shortest overall consultation length was 3 min, whereas the longest overall consultation length was 58 min (range 3–58 min). Within these consultations, several medications and medical instructions were delegated for the patient's therapy.

A more detailed medical analysis of the first month of evaluation can be found in [22]; further results will be published – as described before – after finishing the whole evaluation phase.

# 4 Discussion

## *4.1 Sustainability*

Within the scope of TemRas, the EMS of various districts have been equipped with telemedical components and connected to the TemRas system to generate an added value for patients in an emergency situation. This approach enables faster response times, remotely accessible medical expertise, and high-quality support for the paramedics and the relief of EMS physicians. Using this kind of a system will greatly increase the efficiency in which the resource "EMS physician" can be utilized in the upcoming years by offering the necessary medical competence wherever it is required, without physically sending the physicians into the field when only discretionary competence is in demand.

The consortium will use the acquired knowledge and resources in close cooperation to further enhance the competences in the context of technology, innovation, and medical care. Using the regional transfer possibilities within the different districts of the already involved EMS, it is possible to further efficiently increase the total number of system users until the end of the research project in August 2013. This will result in the creation of working places and further increase the scientific reputation – national and international. Although all partners agree on a continuation of the TemRas system even after the end of the actual research project, it will be crucial to use and intensify the existing contacts and interest of the health insurance companies and work on a plausible collaboration concept to enable a long-term commitment.

Within the project TemRas, the EMS in Germany are comprehensively interdisciplinary cross-linked and uniquely optimized. The collaboration of various institutes and organizations along the medical chain of supply does not only support the sustainable optimization of emergency medical care and an improved service quality but also boosts the economy and science in this field. TemRas can therefore positively change the profile of medical care within Germany and influence the way medical care is implemented. By fostering the competence level of telemedicine, it is both the surrounding rural regions and structural weaker regions within whole Germany that profit. With the first-time rollout of a TRAS on multiple EMS districts, current and future development paths and usability scenarios are demonstrated. The Aachen region, with the first and only implementation of a teleconsultation center, hereby takes the position of a role model for the development and establishment of new working places and infrastructures in the whole of Germany as part of the possible adaptation of the TemRas concept.

Various interest groups have shown clear interest in supporting a long-term operation and integration of the TemRas system; the city of Aachen has expressed the interest of connecting all regional EMS to the TemRas system and therefore wants to equip all ambulances with the needed telemedical components in 2014. At the moment, the consortium is working out different operation and maintenance models and discussing with the different stakeholders to find a consistent solution for a long-term operation scenario, with the focus on not only supporting the city of Aachen itself but also integrating additional districts and regions in neighboring areas.

## 4.2 Impact

The continuation of the research activities to sustainably establish telemedicine within emergency care provides substantial potential for testing innovative medical technologies in this area. During TemRas, for example, new sensor technologies are being developed and evaluated. In addition, synergies regarding different software solution for patient monitoring can be realized; connecting the monitoring system to the teleconsultation center will increase the immediacy of emergency medical care, e. g., during a cardiac insufficiency. There are increased requirements for products in the operation scenario of emergency medicine regarding their robustness, operability, and especially reliability, which result in extended evaluation periods for potential new products in this area.

In general, integrating new IT and medical products into an existing telemedical system requires a lot of expertise and extendable system architecture. The transfer requirements to process the whole variety of vital data plus image and sound data inclusive a digital documentation from the emergency scene to the teleconsultation center are unique, regarding its complexity and reliability. An important criteria for extending the acceptance of users and therefore increase the operation area of the system is its ergonomics and ease of use. The consequent user integration within the development process and sufficient support for the EMS during the implementation period of the product bundle guarantees a future practicability.

The basic result of the project "Med-on-@ix" constitutes that due to scale effects, a cost-efficient operation of such a system will require comprehensive usage. With TemRas, the economical usage of the actual system is evaluated. The necessary scale effects are realized using six ambulances in different regions, and only by using these scale effects does an economically efficient operation of the system become possible. With the possible involvement of the health insurance companies, a successful long-term operation and a future distribution of the necessary product-service bundles can be initiated. The project and all involved partners have continuously been supported by the professional fire service of Aachen. As bearer of the EMS, they are highly interested in optimized and patient-adjusted medical care and are willing to take a leading role in the development of telemedical services within Germany.

The collaboration of the different consortium partners, which has proven to deliver outstanding results in the past, is a good starting point for future projects. In this context, the close connection of TemRas and other telemedicine projects at the RWTH Aachen and the proximity to the Euregio are of great importance. The consequent exchange of knowledge with all involved partners supports the transfer of medical expertise and experience into the development of new clinical products. On the European level, the use of tele-EMS physicians to support nonspecialists in this field will most likely result in a distinct quality augmentation because in many foreign countries, considerably more emergencies are operated by paramedics only. As an explicit example for the model region of Aachen, a transnational teleconsultation center could be implemented to support emergency cases in Germany, the Netherlands, and Belgium alike.

The German emergency care model involving a paramedic and an additional EMS physicians takes a leading role in the quality of emergency services in an international comparison. Nevertheless, an enormous potential for added value still stays unused with the common approach, which is compensated by the utilization of a tele-EMS physician. By further developing the telemedical system TemRas into a market-mature integrated product and service concept, a nationwide system rollout becomes possible, which enables a first-time full-level support for EMS.

The way more efficient and target-oriented utilization of the resource "EMS physician" is a direct approach to counter the estimated EMS physician deficit forecasted for the near future – this deficit is already clearly present within rural regions of Germany. The new professions of a tele-EMS physician as well as the new area of operation described by the teleconsultation center are leading the way toward a new era of emergency medicine. The expansion of the concept enables the creation of new working places in a variety of different fields, e. g., operation, logistics, support, maintenance, distribution of the technical equipment.

**Acknowledgement** This project is performed in collaboration among the RWTH Aachen University, the University Hospital Aachen, and the industrial partners P3 Communications GmbH, Philips Healthcare and 3M Medica. The project is co-funded by the European Union (ERDF – European Regional Development Fund – Investing in Your Future) and the German federal state North Rhine-Westphalia (NRW), under the operational program "Regional Competitiveness and Employment" 2007–2013 (EFRE).

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# Entwicklung soziotechnischer Lösungssysteme im Rahmen der Unterstützung von Normungsarbeit durch eine Web-Kollaborationsplattform

**Alexander an Haack, Eckart Hauck und Sabina Jeschke**

**Zusammenfassung** Auch jede zuerst rein technische oder organisatorische Lösung, wird ab dem Zeitpunkt ihrer Integration in soziale Interessensysteme zwangsläufig zu einer soziotechnischen Lösung. So verhält es sich auch im Falle der Einführung einer Web-Kollaborationsplattform in die bestehenden Strukturen des deutschen Normungswesens. Auch hier kann der Erfolg des Werkzeugs nur dann gewährleistet werden, wenn dieses Teil eines vollständigen soziotechnischen Lösungssystems ist. Die ursprünglichen Lösungselemente müssen hier durch menschliche Agenten, durch organisatorische Regeln und durch weitere technische Maßnahmen so eingebettet werden, dass das volle Potential der Lösung erzielt werden kann. Dies umzusetzen stellt in der organisationalen Praxis jedoch eine bisher nicht systematisch gelöste Problemstellung der Entwicklung komplexer Lösungssysteme dar. Der vorliegende Beitrag diskutiert einen hierauf ausgerichteten Ansatz, den „mininmal-konzeptualisierenden Ansatz", der für die Bedürfnisse praktischer Anwender ohne Expertenwissen des Komplexitätsmanagements entwickelt wurde.

**Schlüsselwörter** Komplexität · Normung · System Dynamics

## 1 Einführung

### *1.1 Hintergrund*

Spätestens mit dem Beginn des 20. Jahrhunderts wurde deutlich, dass Märkte und gesellschaftlicher Wohlstand profitieren, wenn unternehmensübergreifende Standards dem Kunden einheitliche Sicherheits-, Funktionalitäts-, Leistungs- und Robustheitseigenschaften gewährleisten. Gerade sicherheitssensible Anwendungen wie zum Beispiel die Brennstoffzellentechnik (BZT) profitieren wirtschaftlich sehr

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von Normung, da standardisierte Sicherheitsprüfungsverfahren und Standardbauteile die Kosten der Herstellung und Inbetriebnahme der fertigen Geräte senken.

Insbesondere im Fall der Brennstoffzellenbranche offenbart das deutsche Normungswesen jedoch eine Schwachstelle: Normung funktioniert dort, wo etablierte Märkte mit sicheren Umsätzen langfristige Investitionen – wie sie die Normungsarbeit darstellt – finanziell tragen. Die Investitionen der Unternehmen in die Normung umfassen dabei sowohl direkte finanzielle Aufwendungen für Reisetätigkeiten oder Gebühren der Normungsinstitutionen, vor allem aber auch indirekte Kosten durch das potentielle Preisgeben von Know-how und durch Personalbindung. Letztere entsteht zum einen durch die Arbeit zur Erstellung der Norm, zum anderen durch das Aneignen nötigen Normungsprozess- und Kontextwissens. Basierend auf Aussagen von VDMA und VDE zu bisherigen Bemühungen die beschränkten Ressourcen der KMU der BZT für die Normungsarbeit zu bündeln machen diese Aufwendungen die sogenannte „Entwicklungsbegleitende Normung“ (vgl. [1]) gerade für KMU unattraktiv. Ein Umstand, der bereits in den Anfangstagen der Normung beschrieben wurde ([2] S. 1084): „so ist doch trotz der Veranstaltung so vieler internationaler Kongresse und Bildung internationaler Kommissionen bisher eigentlich nur in solchen Gebieten ein gewisser Erfolg erzielt worden, in denen größere finanzielle Interessen mit derartigen Vereinbarungen Hand in Hand gingen.“

Seit der Blüte des Informationszeitalters existieren im Grundsatz technische Mittel, um den nötigen Aufwand für die gemeinschaftliche Erstellung und Abstimmung von Normen signifikant zu reduzieren. Im Rahmen einer industriebegleiteten Forschungsarbeit[1] wird eine systemunabhängige Web-Kollaborationsplattform für das Erstellen von Normen entwickelt. Die größten Potentiale dieses IT-Werkzeugs wurden dabei in der Verbesserung der Transparenz der relevanten Informationen für die Normungsarbeit sowie in der Einfachheit und Beschleunigung der Kommunikation zwischen den Normungsteilnehmern und der deren Beitragsleistungsmöglichkeiten identifiziert. Mit Hilfe einer optimalen Integration der Funktionalitäten Kollaboration, Kommunikation und Information bietet die IT-Unterstützung eine zeit- und orts-unabhängige Teilnahme am Normungsprozess sowie eine optimale Unterstützung der interessierten Kreise mit Normungsfachwissen.

## *1.2 Die erfolgreiche Integration eines IT-Werkzeugs in die bestehenden Strukturen des Normungswesens als soziotechnisches Lösungssystem*

Die sogenannte Mensch-Maschine-Schnittstelle, auch „User Interface“ (vgl. [3]), hat einen wesentlichen Anteil an der nutzerseitigen Akzeptanz technischer Werkzeuge.

[1] Ein durch das BMWi gefördertes AiF-Forschungsprojekt des Institut für Unternehmenskybernetik und des Zentrum für Brennstoffzellentechnik, s. www.normes.de.

Hierbei geht es darum, inwieweit sich das Werkzeug für die individuellen Fähigkeiten und Nutzungsszenarien der potentiellen Nutzer eignet. Dies ist ein zentraler Faktor für die Frage, ob die Leistungsfähigkeit des Werkzeugs im praktischen Einsatz tatsächlich realisiert wird. Die angestrebte Lösung beinhaltet somit grundsätzlich auch eine soziotechniche Fragestellung. Ein soziotechnisches System besteht aus menschlichen (Individuen und/oder Gruppen) und technischen Subsystemen, die temporär oder dauerhaft über explizite und/oder implizite Interaktionsmuster miteinander in Wechselwirkung stehen. Die soziotechnische Herausforderung der geschilderten Problemstellung IT-Unterstützung des Normungsprozesses reicht jedoch weiter. Dies ergibt sich aus dem Umstand, dass das entwickelte Werkzeug nicht ohne die Unterstützung der Normungsgesellschaften[2] effektiv sein kann. Die hoheitliche Zuweisung der Organisation von Normungsaktivitäten an jeweils eine nationale Normungsgesellschaft[3] verbietet diese Möglichkeit. Die Web-Kollaborationsplattform kann somit nur Erfolg haben, wenn es gelingt es in die bestehenden Strukturen der Normungsgesellschaften zu integrieren. Somit umfasst die soziotechnische Herausforderung nicht nur das Schaffen von Akzeptanz auf Seiten des Nutzers, sondern auch auf Seiten der Normungsgesellschaften.

Konkret besteht das Konfliktpotential einer derartigen, angestrebten Integration darin, dass eine Initiative außenstehender Akteure[4] beabsichtigt, in die bestehenden Prozesse und die eigenen Strategien der Akteure des deutschen Normungswesens einzugreifen. In der Konsequenz erlangt der politisch-organisatorische Teil der soziotechnischen Dimension des Lösungssystems eine dominante Bedeutung für den nachhaltigen Erfolg der Innovation. Zentrales Ziel dieser kybernetischen Forschung ist daher das Ermöglichen einer möglichst optimalen Integration der psychosozialen Wirkungen der Systemumwelt im Gesamtlösungssystem (hier: „IT-Unterstützung des Normungsprozesses").

Im vorliegenden Beitrag wird ein Ansatz vorgestellt, der darauf abzielt, die Schwächen bisheriger Ansätze zur Entwicklung soziotechnischer Lösungssysteme zu vermeiden. Diese wurden im Vorfeld vor allem in verhindernden Voraussetzungen der Ansätze für praktische Anwender sowie in deren Kontextabhängigkeit ausgemacht. Unter einem praktischen Anwender wird hier ein Individuum (oder eine Gruppe) verstanden, das ohne systematische Vorbildung über soziotechnische Systeme in diesem Kontext Lösungen entwickelt. Häufig auftretende Beispiele, mit relevantem soziotechnischem Anteil an der Problemstellung, sind Organisationsentwicklungsmaßnahmen durch Führungskräfte im mittleren Management, Technik getriebene Produktentwicklungen durch entsprechende Ingenieure oder die Gestaltung bürokratischer Prozesse durch Verwaltungsangestellte. Bei derartigen Fällen

[2] Dies sind die von der Bundesregierung für die Normung benannten Stellen. Im wesentlichen sind dies (1) DIN Deutsches Institut für Normung e. V. und (2) DKE Deutsche Kommission Elektrotechnik Elektronik Informationstechnik im DIN und VDE.

[3] In Deutschland wird die DKE im Sinne der Normung als Teil des DIN verstanden.

[4] Gemeint sind die in NormEs tätigen Forschungsstellen sowie die darin beteiligten Unternehmen.

wird im vorliegenden Forschungsvorhaben davon ausgegangen, dass die jeweils verfügbaren Ressourcen in der Praxis eine hinreichende systemtheoretische Ausbildung der Lösungsentwickler verhindern.

Im Anschluss an dessen Vorstellung wird die Anwendung des Ansatzes auf die Analyse und den Lösungsweg der Problemstellung des auf maximale Integrationswahrscheinlichkeit fokussierten Lösungssystems „IT-Unterstützung des Normungsprozesses“ beschrieben.

## 2 Ein für die Bedürfnisse praktischer Anwender entwickelter Ansatz zur Entwicklung soziotechnischer Lösungssysteme

### *2.1 Allgemeine Ansätze zur Entwicklung soziotechnischer Lösungen*

Die Entwicklung soziotechnischer Lösungssysteme kann seit der Begründung des Soziotechnik-Begriffs in den 1960’er Jahren (vgl. [4]) auf zahlreiche Ansätze der Kybernetik, des Systems Engineering, des systemorientierten Managements sowie anderer Disziplinen mit entsprechenden Schnittmengen zurückgreifen. Unter einem soziotechnischen Lösungssystem wird hier eine systematische Kombination aus menschlichen Agenten (von Individuen oder Gruppen erfüllte Funktionen) und technischen Hilfsmitteln verstanden, die über gezielte Interaktionsmuster (implizite und explizite Regeln) organisiert sind, um eine intendierte Problemlösung herbeizuführen. Im Allgemeinen geht es bei diesen Ansätzen stets darum, die naturbedingte Komplexität soziotechnischer Problemsysteme so handhabbar zu machen, dass das Entwickeln verlässlicher Lösungssysteme möglich wird. Es handelt sich somit um Hilfsmittel zur Qualitätssicherung in der Entwicklung soziotechnischer Lösungen. Im Rahmen dieser Forschungsarbeit wurden in einer ersten Untersuchung zur Systematisierung bestehender Hilfsmittel vier unterschiedliche Kategorien identifiziert[5]:

- Verständnismodelle: Hierbei handelt es sich um abstrakte Systematisierungen der (meist für eine eingegrenzte Problemstellung) relevanten Bestandteile eines Lösungssystems sowie deren Wechselwirkungen. Diese dienen insbesondere dem besseren Verständnis des Verhaltens und Aufbaus eines bestimmten Systemtyps mittels Übertragung des abstrakten Modells auf die Realität. Beispiele sind das Viable System Model (vgl. [5]) und das OSTO Systemmodell (vgl. [6]).
- Modellierung & Simulation: Ein anderer Weg der Handhabung einer konkreten komplexen Problemstellung ist deren zielgerichtete, modellhafte Abbildung, die

[5] Auf Grund des Fokus auf praktische Anwender werden an dieser Stelle ausschließlich Methoden betrachtet, die - entsprechende Methodenkenntnis vorausgesetzt - ohne weitere Vorbereitung vom Lösungsentwickler angewandt werden können. Explorative Analysen, die entsprechend verfügbare Daten voraussetzen, bleiben somit außen vor.

häufig auf das vollständige Berücksichtigen sogenannter weicher Faktoren bedacht ist. Das Ziel ist, auf Basis einer methodischen Erfassung und Verrechnung aller relevanten Faktoren und Wechselwirkungen, Prognosen über das Verhalten des Systems zu ermöglichen. Beispiele sind die System Dynamics (vgl. [7]) und das Agent-Based Model (vgl. [8]).

- Designprinzipien: Dieser Ansatz der Komplexitätshandhabung geht davon aus, dass auch komplexem Systemverhalten disziplinübergreifende, abstrakte Muster zu Grunde liegen. Auf dieser Basis ist es möglich in gewissem Rahmen allgemeingültige Verhaltensprinzipien zu formulieren, die diese Muster widerspiegeln. Werden diese Prinzipien bei der Entwicklung komplexer Lösungssysteme berücksichtigt, ist sichergestellt, dass die entwickelte Lösung zumindest die von den Prinzipien abgedeckten komplexen Phänomene respektiert. Dies kann für den Anwender die empfundene Komplexität einer Problemstellung praktisch vollständig auflösen. Beispiele sind die acht Grundregeln der Biokybernetik (vgl. [9] S. 154–183) und die Design Principles for CPR Institutions (vgl. [10]).
- Vorgehensmodelle: Dies sind – insbesondere aus der Bewegung des systemorientierten Managements – stammende Anleitungen (z. T. inkl. Methodiken), die dem Anwender eine pragmatische Handlungs-abfolge zur Lösungsentwicklung vorgeben. Im wesentlichen handelt es sich hierbei um systematisierte Problemlösezyklen, die zusätzlich die Besonderheiten komplexer soziotechnischer Problemstellungen berücksichtigen. Beispiele sind die Soft Systems Methodology (vgl. [11]) und in Teilen die Sensitivitätsanalyse (vgl. [9] S. 185–263).

Im Sinne einer maximalen Beherrschung einer komplexen Problemstellung ist grundsätzlich die Kombination aller vier Arten sinnvoll. Der hier vorgestellte Ansatz nutzt ebenfalls Methoden aller vier Kategorien. Die zentralen Merkmale bilden ein Systemmodell und ein Designprinzip, die insbesondere auf eine Eignung für praktische Anwender ausgerichtet sind.

## *2.2 Der minimal-konzeptualisierende Ansatz zur Entwicklung soziotechnischer Lösungssysteme*

Der minimal-konzeptualisierende Ansatz basiert auf der Zielstellung, komplexe, soziotechnische Problemsituationen nicht nur prinzipiell hand-habbar zu machen, sondern dies vor allem für praktische Anwender zu leisten. Die Entwicklung des Ansatzes fokussierte daher nicht auf die Zusammenstellung von Methoden für ein maximal mögliches Komplexitätsmanagement, wie es in Kombination mit Expertenanwendern möglich wäre. Dem Ansatz hinzugefügt wurden lediglich Elemente, von denen Ausgegangen wurde, dass deren Anwendung in der Praxis ohne Methoden- und nur mit geringem Kontextwissen erfolgreich ist. Als Kernproblematik einer geringen Eignung bisheriger Modelle für praktische Anwender werden deren

Vorraussetzung von Vorwissen[6] sowie deren starke Kontextabhängigkeit[7] gesehen. Um die Zielstellung zu erreichen, nutzt der Ansatz daher nur ein einziges Designprinzip sowie ein Verständnismodell mit einem Minimum expliziter und impliziter Konzepte, die von Anwendern in Frage gestellt werden könnten. Ein Konzept stellt in diesem Zusammenhang eine zielgerichtete, sinnbehaftete, gruppierte Auffassung von Teilelementen der wahrgenommenen Realität durch den Menschen dar. Das Ziel dieser gerichteten Auffassung ist die Reduktion der erlebten Komplexität der Realität durch deren Einteilung in Subsysteme mit subjektiver Bedeutung, d. h. relativ zum Betrachter und dessen aktueller Situation. Die Forderung nach einem Minimum implizit verwendeter Konzepte ist äquivalent mit einem maximalen Abstraktionsniveau der explizit verwendeten Konzepte.

Grundlage des Ansatzes ist ein die Realität „minimal-konzeptualisierendes Systemmodell" (MKSM). Aufbauend auf einer physikalischen Betrachtung bestehen Systeme hierin ausschließlich aus *Wirkungen*, die durch Interferenz wiederum resultierende (emergente) Wirkungen erzeugen. Analog zum Versklavungsprinzip ([12] S. 296) lässt sich nun für jedes betrachtete System eine momentan dominierende Wirkung identifizieren, die entweder dem Gesamtsystem, einem Umweltsystem oder einem Sub-System zuzuordnen ist. Der hier beschriebene Status der „dominierenden Wirkung" gilt somit immer nur in Bezug auf ein spezifisches Verhalten (z. B. Reaktion auf ein neues IT-Werkzeug) des beobachteten Systems (z. B. das deutsche Normungswesen) zu einem bestimmten Zeitpunkt. In der detaillierten Analyse der gesamten Prob-lemstellung können somit lokal auch mehrere dominierende Wirkungen identi-fiziert werden, die aktuell jeweils das Verhalten ihres Teil-Systems bestimmen.

Da jede Wirkung stets nur in Richtung eines lokalen Potentialminimums ablaufen kann, ist neben der Wirkung auch stets die abstrakte Ursache der dominierenden Wirkung bekannt. Bezogen auf lebende Systeme entspricht diese Ursache jedweden Systemverhaltens der Erhöhung der Lebensfähigkeit (vgl. [5] S. 7 f.; [9] S. 49), bzw. der Entwicklung in Richtung lokaler Maxima der Lebensfähigkeitsfunktion. Lebensfähigkeitsfunktion und Lebensfähigkeit beschreiben abstrakt die Eignung eines Systems unter den für es relevanten Bedingungen fortzubestehen. Im Falle psycho-sozialer Systeme beinhaltet dies insbesondere auch den Gemütszustand, da dieser die Leistungsfähigkeit zum Erhalt des Systems beeinflusst.

In vergleichbarer Weise, wie die Verständnismodelle von Beer und Vester auf dem Primat der Lebensfähigkeit beruhen, gibt der vorliegende Ansatz dem praktischen Anwender die Maximierung der Lebensfähigkeit als einziges Designprinzip vor, welches er bei der Analyse und Entwicklung soziotechnischer Systeme zu betrachten hat. Für ein soziotechnisches System – dessen Existenzgrund immer in der Verbesserung der Lebensfähigkeit von psychosozialen Systemen liegt – bedeutet dies, zu betrachten, ob es seine Nutzersysteme optimal unterstützt und wie dies

[6] Insbesondere bei Verständnismodellen und bei Modellierung & Simulation.

[7] Insbesondere bei Designprinzipien und bei Vorgehensmodellen.

zu verbessern wäre. Durch die Einschränkung auf dieses eine Designprinzip werden dem Anwender zwar zahlreiche, in spezifischen Fällen sehr hilfreiche Konzepte vorenthalten, im Gegenzug eröffnet das Vorgehen jedoch folgende Vorteile:

- Einfachheit: Die extreme Beschränkung der Betrachtung jedes Systems nach einer einzigen, einfachen Regel bedeutet, dass der Anwender unabhängig von der Komplexität des Systems zu jedem Zeitpunkt einen Anhaltspunkt für dessen Analyse und Gestaltung hat. Er wird somit nicht bereits von den Voraussetzungen des Ansatzes selbst überfordert.
- Kontextunabhängigkeit: Der Fokus auf das einzig entscheidende und immer gültige Kriterium Lebensfähigkeit vermeidet automatisch die Fehlerquelle der Annahme situativ nicht zutreffender Konzepte.
- Selbstbestimmtheit: Aufbauend auf dem leicht nachzuvollziehenden Prinzip der Lebensfähigkeitsmaximierung werden bei diesem Ansatz ausschließlich Annahmen über das System in die Lösung integriert, denen der Anwender selbst in der jeweiligen Situation auch vertraut. So alle relevanten Interesseneigner in diesen Prozess korrekt einbezogen werden, entsteht somit eine Lösung, die maximal frei von nicht unterstützten Konzepten ist.
- Lerneffekt: Da dem Anwender lediglich der grundlegende Ansatz zum Verständnis des Verhaltens von Systemen zur Verfügung gestellt wird, ist dieser gezwungen, sich ein ursächliches Verständnis der beteiligten Systeme und somit der Problemstellung zu erarbeiten. Dies sorgt für einen maximalen Lerneffekt für zukünftige Problemstellungen.
- Reduktion von Lösungskomplexität: Bei der Ermittlung der für die Lösung relevanten Wirkungen, wird automatisch nur nach jenen gefragt, die eine Relevanz für die Lebensfähigkeit der beteiligten Systeme haben. Die Komplexität der Lösungsmenge wird somit maximal reduziert.

Um diese Vorteile dem praktischen Anwender optimal zugänglich zu machen, wurde der minimal-konzeptualisierende Ansatz in ein eigenes Vorgehensmodell zur Gestaltung soziotechnischer Systeme eingebettet. Grundlage dessen ist der allgemeingültige Umstand, dass die Vitalität jedes Systems optimal gefördert wird, wenn seine Lebensfähigkeitsfunktion als möglichst positiver Bestandteil in diejenigen seiner Umwelt- und Sub-Systeme eingeht (vgl. [9] S. 164–169). In grober Darstellung fordert das Vorgehensmodell folgende Schritte:

1. Relativ zum interessierenden Verhalten des betrachteten Systems erfolgt die Identifikation derjenigen Teil-Systeme der Problemstellung, die aktuell den Status Quo dominieren[8].
2. Nach der Identifikation der relevanten Teil-Systeme findet die Modellierung von deren Lebensfähigkeitsfunktionen statt, d. h. insbesondere deren dominierender Wirkungen.

[8] Dies umfasst insbesondere klassische Interesseneignersysteme wie Kunden, Handelnde und Besitzer (vgl. [11]).

3. Aufbauend auf den Lebensfähigkeitsfunktionen der dominanten Teil-Systeme erfolgt der Entwurf der optimalen Lebensfähigkeitsfunktion des betrachteten Lösungssystems.
4. Basierend auf der theoretisch optimalen Lebensfähigkeitsfunktion des Lösungssystems erfolgt dessen praktische Umsetzung. Diese muss mindestens (1) die dominierende Wirkung des Status quo des Gesamtsystems und möglichst (2) die dominierenden Wirkungen aller relevanter Teil-Systeme im Sinne einer maximalen Unterstützung der Lebensfähigkeitsfunktion des Lösungssystems nutzen.
5. Schließlich findet eine Beurteilung der Richtung der natürlichen, zeitlichen Entwicklung der Wirkungen der Teil-Systeme in Reaktion auf das Lösungssystem statt. Die Zentrale Frage hierbei ist, ob die vermutete Entwicklung sich positiv oder negativ auf die Ausgangssituation das Lösungssystem auswirkt, d. h. wie nachhaltig die Lösung ist.

Der gesamte beschriebene Ablauf wird während der Entwicklung iterativ durchlaufen. Methodisch eignet sich für die Modellierung die Nutzung der qualitativen Modelle der System Dynamics zur Darstellung von Wirkungsketten (vgl. [13] S. 144). Für die Validierung der Systemmodelle und der zu Grunde liegenden Annahmen eignen sich wiederkehrende Expertenbefragungen nach dem Prinzip der Delphibefragung sowie quantitative Plausibilitätstests der Wirkungszusammenhänge.

## *2.3 Der minimal-konzeptualisierende Ansatz am Beispiel des Vorhabens IT-Unterstützung des Normungsprozesses*

Für das soziotechnische Lösungssystem „Einsatz einer hochintegrierten Web-Kollaborationsplattform zur Beschleunigung, Automatisierung und Verbesserung des Normungsprozesses im Bereich Brennstoffzellentechnik“ (Vorhaben NormEs) sind auf der ersten Abstraktionsebene neben dem technischen System fünf Teilsysteme relevant. Dies sind

- die potentiellen Teilnehmer der Normungsarbeit,
- die Normungsgesellschaften (DIN und DKE),
- die Fachverbände (u. a. VDMA),
- das Bundesministerium für Wirtschaft (BMWi) sowie
- die deutsche Zivil-Gesellschaft.

Die dominierende Wirkung des Status Quo – d. i. kein Einsatz einer vergleichbaren Lösung – muss daher in einem dieser Teilsysteme begründet sein. Dies kann gefolgert werden, da der Realisation eines größeren Nutzens durch IT-unterstützte Normenerstellung grundsätzlich keine unüberwindbaren technischen, organisationalen oder finanziellen Hürden im Wege stehen. Festzustellen ist hierbei, dass der technisch-organisatorische Bestandteil der antizipierten Lösung – das IT-Werkzeug und seine

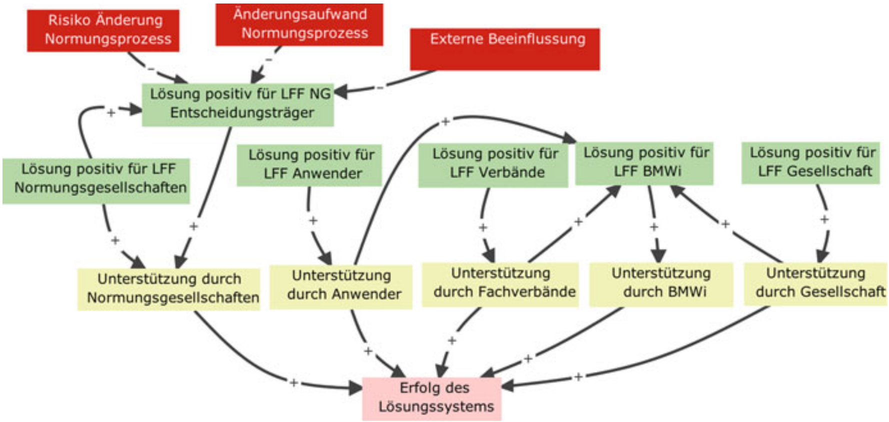


**Abb. 1** Simplifizierte Darstellung des Lösungssystems NormEs, der Lebensfähikgeitsfunktionen (*LFF*) der relevanten Teilsysteme und der vier primären Wirkungszusammenhänge, die das dominierende Teilsystem Entscheidungsträger der Normungsgesellschaften (*NG*) betreffen

organisatorische Einbettung in die Normungsaktivitäten – unter die Entscheidung der Normungsgesellschaften (NG) fällt[9]. Da keine sonstigen verbietenden Wirkungen festzustellen sind[10] lässt sich die Suche nach der dominierenden Wirkung auf die beteiligten Normungsgesellschaften eingrenzen und innerhalb dieser wiederum auf deren Entscheidungsträger (vgl. Abb. 1).

Erforderlich ist daher die Identifikation der Ursachen für das Verhalten der Entscheidungsträger der Normungsgesellschaften. Gerade die Analyse und die Prognose menschlicher Verhaltensweisen können auf Grund von deren hoher Komplexität für den praktischen Anwender leicht zur ungeordneten Problemstellung werden. Um die unterschiedlichen Wirkungen sachlich und somit auch zustimmungsfähig zu erfassen, wird gerade an dieser Stelle der Fokus auf die Modellierung der Lebensfähigkeitsfunktion des betrachteten Systems gelegt.

Unter Zuhilfenahme gebräuchlicher Motivationsklassifikationen[11] lassen sich so auf nachvollziehbare Weise die Wirkungen des Lösungssystems mit den Interessen des betrachteten psychosozialen Systems verknüpfen. Im vorliegenden Fall wurden primär folgende Wirkungs-Interessen-Relationen identifiziert:

- Mehr „Risiken durch Änderung der Normungsprozesse“ (Wirkung) führt kurzfristig direkt zu weniger „Sicherheit“ auf Seiten der Entscheidungsträger (Interesse).
- Mehr „Änderungsaufwand für die Entscheidungsträger“ (Wirkung) führt kurzfristig direkt zu weniger „Zielerreichungseffizienz“ der Entscheidungsträger (Interesse).

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[9] Diese sind per Gesetz exklusiv für diese Aufgabe benannt.
[10] Z. B. Widerstände in der Gesellschaft, gesetzliche Verbote, etc.
[11] Z. B. Maslowsche Bedürfnishierarchie (vgl. [15]).

- Mehr „externe Beeinflussung der Aktivitäten der Normungsgesellschaft“ (Wirkung) führt kurzfristig direkt zu weniger „Selbstbestimmung der Entscheidungsträger“ (Interesse).
- Mehr „Lebensfähigkeit der Normungsgesellschaft als Institution“ (Wirkung) führt langfristig direkt zu mehr „Sicherheit“, „Zielerreichungseffizienz“, „Selbstbestimmung“, „berufliche Weiterentwicklung“ auf Seiten der Entscheidungsträger (Interesse).

Hieraus ergibt sich automatisch, dass das resultierende Lösungssystem die drei kurzfristigen, negativen Wirkungen soweit reduzieren muss, dass diese den Erwartungswert ([14] S. 402) der langfristigen positiven Wirkungen unterschreiten. Zudem bieten sich kreative Lösungsmöglichkeiten an, die die identifizierten dominanten Interessen des Status Quo gezielt adressieren und somit zusätzliche Anreize setzen. Dabei muss jedoch darauf geachtet werden, dass derartige Anreize die Lebensfähigkeit des Gesamtsystems langfristig kumuliert nicht reduzieren.

Im Fall des Vorhabens NormEs resultieren aus den unterschiedlichen Ausgangssituationen der beiden deutschen Normungsgesellschaften (DIN, DKE) zwei unterschiedliche Bewertungen der oben beschriebenen Wirkungs-Interessenkonstellation. Konkret bietet es sich daher an, insbesondere die negativen Wirkungen „Risiko“ und „Änderungsaufwand“ für die eine Normungsgesellschaft dadurch zu reduzieren, indem das Lösungssystem bei der anderen Normungsgesellschaft zuerst erprobt wird.

## 3 Fazit und Ausblick

Der minimal-konzeptualisierende Ansatz zur Gestaltung soziotechnischer Lösungssysteme wurde mit Bezug auf die Problemstellung im Forschungsvorhaben NormEs vorgestellt. Ziel der Anwendung des Ansatzes ist, eine erfolgreiche soziotechnische Lösung zu entwickeln, die insbesondere für die beteiligten Interesseneigner der Problemsituation als für ihre Lebensfähigkeitsfunktion (Interessen) förderlich erkannt wird. Die zentralen Elemente des Ansatzes sind das minimal-konzeptualisierende System Modell (MKSM) und der Fokus auf das Designprinzip der Maximierung der Lebensfähigkeitsfunktion der beteiligten Systeme. Beispielhaft wurde gezeigt, wie sich diese charakteristischen Merkmale auf die Entwicklung des soziotechnischen Lösungssystems der Web-Kollaborationsplattform NormEs auswirken.

Im weiteren Verlauf der Forschung zum vorgestellten Ansatz zur Entwicklung soziotechnischer Lösungssysteme mit der Zielgruppe praktischer Anwender gilt es, dessen vermutete Mehrwerte weiter zu verifizieren und insbesondere die Anwenderfreundlichkeit zu erhöhen. Letzteres kann beispielsweise durch eine praktisch erprobte Systematisierung der potentiellen Einflüsse auf die Lenbensfähigkeitsfunktionen von psychozialen Systemen – d. h. Individuen oder Gruppen - erfolgen. Hierbei muss gewährleistet sein, dass die Mehrwerte der minimalen Konzeptualisierung nicht gefährdet werden.

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# Kreativität mit System – Innovationsmanagement strategisch umsetzen

**Alan Hansen, Frank Hees und Anja Richert**

**Zusammenfassung** Dass Unternehmen dynamisch und flexibel auf Einflüsse aus der Umwelt reagieren müssen um Ihre Wettbewerbsfähigkeit zu sichern ist keine wirklich neue Erkenntnis. Aktuell aber sieht sich die deutsche Wirtschaft mit besonders folgenreichen Entwicklungen konfrontiert, die sich sowohl auf das individuelle Verhalten der Mitarbeiter als auch auf die Organisation als Ganzes auswirken. Ob demografischer Wandel, Virtualisierung von Produktionsprozessen, Cloud Services, Social Trademarks, verkürzte Produktlebenszyklen oder Crowdsourcing – die gegenwärtigen gesellschaftlichen, ökonomischen und technologischen Trends stellen Unternehmen vor besondere Herausforderungen. Die Lösung scheint klar. Innovationen müssen her – schneller, höher, weiter und besser. Doch was sind überhaupt Innovationen? Und welche Strategien und Maßnahmen können Unternehmen ergreifen, um ihre Innovationsfähigkeit zu erhöhen und langfristig zu sichern?

**Schlüsselwörter** Innovationsfähigkeit · Innovationsstrategie · Innovationsmanagement

## 1 Mehr als Produkte und Technologien

Insbesondere Unternehmen in hochentwickelten Volkswirtschaften sind massiv gefordert, ihre Innovations- und damit Konkurrenzfähigkeit gegenüber den globalen Mitbewerbern in den Schwellenländern zu behaupten. Innovationen werden gebetsmühlenartig von Politikern und Unternehmern als universale Heilsbringer für die nachhaltige Sicherung des ökonomischen Erfolgs gefordert. Es war nicht der US-Gigant Apple, der das MP3-Standardformat zur Speicherung und Übertragung von Audiodaten erfunden hat, sondern das Fraunhofer Institut für Integrierte Schaltungen

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(IIS) in Mittelfranken im Jahre 1982. Letztendlich war es jedoch wieder Apple-Ikone Steve Jobs, der das Marktpotenzial der technologischen Neuerung als Erster erfasste: Neben dem auf das MP3-Format ausgerichteten IPod mit dem Musikservice ITunes, wurde auch eine adäquate User-Schnittstelle am Markt etabliert. Entstanden ist ein ganzheitliches global funktionierendes Geschäftsmodell, das das Verhalten der Musikhörer revolutioniert hat und Apple derzeit geschätzte acht Milliarden Euro Umsatz pro Jahr beschert. Das Fraunhofer IIS hingegen muss sich bei den Einnahmen aus dem MP3-Lizenzgeschäft mit 16 Mio. € begnügen. [1]

Das Beispiel zeigt, dass Innovationen weit über die rein technologische Dimension hinaus gedacht werden müssen. Eine Innovation kann neben einem ökonomischen, insbesondere auch einen sozialen oder ökologischen Butzen mit sich bringen und Unternehmen dadurch auch unmittelbaren oder mittelbaren monetären Erfolg bescheren. Neben Produkt- und Dienstleistungsinnovationen gibt es noch eine ganze Reihe weiterer Innovationsarten wie Prozessinnovationen, soziale Innovationen oder Strukturinnovationen, die zum wirtschaftlichen Erfolg von Unternehmen beitragen können. Doch wie kann es einem Unternehmen gelingen, möglichst viele dieser Innovationspotenziale effizient zu nutzen?

## 2 Innovationsförderliche Rahmenbedingungen

Eine wesentliche Voraussetzung dafür ist, dass Mitarbeiter ihre individuellen Kompetenzen und ihre Kreativität für die Entwicklung neuer Produkte, Prozesse oder Strukturen einsetzen können und wollen. Daher sind Unternehmen und insbesondere Führungskräfte gefordert, innovationsförderliche Arbeits- bzw. Rahmenbedingungen zu schaffen, die Mitarbeiter nachhaltig darin unterstützen, ihre Potenziale kontinuierlich und in möglichst effizienter Weise einzubringen.

Die Etablierung derartiger Innovationsförderlicher Rahmenbedingungen kann sich jedoch nicht auf die Einrichtung einer weitestgehend vom Rest des Unternehmens isoliert agierenden FuE-Abteilung beschränken. Stattdessen müssen die Führungskräfte das gesamte soziotechnische System (ihr Unternehmen), inklusive aller Mitarbeiter, auf die Entwicklung von Ideen und die Umsetzung von Innovationen ausrichten. Diese ganzheitliche Perspektive auf Innovationsfähigkeit impliziert, dass die Entstehungsbedingungen von Innovationen vielschichtig sind und in wechselseitiger Weise von den Faktoren Mensch, Organisation und Technologie abhängen. [2]

Erst diese systemorientierte und integrierte Betrachtung aller drei Ebenen befähigt ein Unternehmen dazu, nachhaltig innovationsfähig zu sein. Innovationsfähigkeit umfasst das komplexe Zusammenspiel der menschlichen, organisationalen und technologischen Voraussetzungen zur kontinuierlichen Hervorbringung von Innovationen. Doch welche Orientierungs- und Planungshilfen stehen Führungskräften zur Verfügung, um den komplexen Herausforderungen der modernen Arbeitswelt systematisch begegnen zu können?

## 3 Innovationsfähigkeit steigern

Im Rahmen des an der Rheinisch-Westfälischen Technischen Hochschule (RWTH) Aachen University durchgeführten Projekts International Monitoring [3] fanden von 2008 bis 2012 umfangreiche Arbeiten zur Erforschung der ganzheitlichen Innovationsfähigkeit von Organisationen statt. Die verschiedenen transdisziplinären Aktionsfelder umfassten dabei u. a. nationale und internationale Expertenarbeitskreise, Summer- und Winter Schools, Online-Befragungen und Trend-Studien. Eine zentrale Erkenntnis des Vorhabens ist, dass die systematische Ausgestaltung einer ganzheitlichen Innovationskultur (in Form von entsprechenden Rahmenbedingungen) entscheidend für die Realisierung einer kontinuierlichen Innovationsfähigkeit ist. Im Laufe des Projekts konnten 11 übergreifende Strategien identifiziert und definiert werden, die als Orientierungs- und Planungshilfen zur Etablierung einer nachhaltigen Innovationskultur in Organisationen fungieren.

Darüber hinaus wurde der Strategieplaner innoBOOST entwickelt. Das kostenlos nutzbare Online-Tool bietet Führungskräften die Möglichkeit, eine nachhaltige, selbständige Diagnose zur Innovationsfähigkeit der eigenen Organisation auf Basis der Forschungserkenntnisse des International Monitoring durchzuführen. Dabei werden die identifizierten innovationsförderlichen Strategien in Bezug auf menschliche, organisationale und technische Aspekte verständlich erläutert und vor den spezifischen Gegebenheiten der jeweiligen Organisation analysiert. Folgende Innovationsstrategien werden in diesem Kontext detailliert untersucht und erläutert: [4] (Abb.1)

1. *Gesundheits- und Präventionsmanagement*
   Die Gesundheit der Mitarbeiter stellt eine elementare Voraussetzung der Innovationsfähigkeit von Unternehmen dar. Dabei korrespondiert die steigende gesundheitliche Belastung häufig mit einem Mangel an ökonomisch und sozial tragfähigen Strukturen zur betrieblichen oder betriebsunabhängigen Prävention und Gesundheitsförderung.
2. *Etablierung von Innovationskulturen*
   Die Frage nach Unternehmenskulturen, die die Innovations- und Wettbewerbsfähigkeit fördern, gewinnt vor dem Hintergrund globalisierter Arbeitsmärkte, multikultureller Belegschaften und divergierender Wissensbestände zusätzlich an Bedeutung. Diesbezüglich muss die Entwicklung einer unternehmerischen Kultur angestrebt werden, die einen Nährboden für kontinuierliches innovatives Handeln bildet.
3. *Nutzung von Wissen und Humanpotential*
   Wissen und Humanpotential sind entscheidende Triebfedern der Innovationsfähigkeit. Insbesondere vor dem Hintergrund der zunehmenden Tertiarisierung und Quartarisierung sowie des demografischen Wandels und des damit zusammenhängenden Fachkräftemangels gewinnt die systematische Weiterentwicklung von Humanressourcen zunehmend an Bedeutung.


**Abb. 1** 11 Strategien (S) zur Gestaltung innovationsförderlicher Rahmenbedingungen

4. *Ganzheitliches Innovationsmanagement*
   Die Fähigkeit Innovationen hervorzubringen steht und fällt mit der Fähigkeit Innovationsprozesse ganzheitlich und systemisch zu managen. Im Zuge des Übergangs zur Wissens- und Dienstleistungsgesellschaft stellen moderne Ansätze in dieser Hinsicht vor allem das Management von immateriellen Ressourcen in den Mittelpunkt, um möglichst alle Prozesse der Generierung, Beurteilung, Anwendung und Implementierung von Wissen und Inventionen mit einzubeziehen.

5. *Fokussierung sozialer und organisationaler Innovationen*
   Soziale und organisationale Innovationen werden in der deutschen Wirtschaft bislang wenig und zumeist nur in Bezug auf technische Innovationen zur Kenntnis genommen und analysiert. Mit dem Wandel zur Wissens- und Dienstleistungsgesellschaft zeichnet sich ein Paradigmenwechsel im Innovationsverständnis ab: Derartige weiche Innovationsarten finden in der Praxis verstärkt Anerkennung, da sie einen signifikanten Einfluss auf die Innovationsfähigkeit von Organisationen haben und zu einer erhöhten Wertschätzung des Humanpotentials beitragen können.
6. *Öffnung von Innovationsprozessen*
   Die voranschreitende Digitalisierung und virtuelle Vernetzung von Akteuren sowie die Erweiterung der Kundenorientierung um die Kundeninnovation ziehen neue Konstellationen für die Innovationsfähigkeit nach sich. Unternehmen müssen sich diese neuen Voraussetzungen strategisch zunutze machen, indem sie die innovativen Potenziale von internen und externen Stakeholdern von Beginn an in Innovationsvorhaben integrieren.
7. *Kontinuierliche Kompetenzentwicklung*
   Die wachsende ökonomische Dynamik sowie die demografische Entwicklung verlangen, neben der Etablierung einer Migrationskultur und der langfristigen Gesunderhaltung der Arbeitskräfte, eine systematische und lebenslange Lern- und Kompetenzentwicklung, die eine neue individuelle Verantwortung sowie veränderte Berufsbiographien und Qualifizierungsanforderungen impliziert.
8. *Integrative Gestaltung von Arbeits- und Lernwelten*
   Die zur Stärkung der Innovationsfähigkeit notwendigen individuellen und organisationalen Lernprozesse können unter dem vorherrschenden Zeitdruck nur durch die synergetische Integration von Arbeiten und Lernen realisiert werden. Erforderlich ist dafür u. a. ein systematischer Ausbau informeller Lernmöglichkeiten innerhalb der Arbeitsprozesse.
9. *Work-Life-Balance*
   Ganzheitliche Konzepte zur Förderung der Innovationsfähigkeit beinhalten auch Maßnahmen zur Etablierung und kontinuierlichen Aufrechterhaltung einer Balance zwischen Arbeits- und Privatleben. Damit stehen Unternehmen vor der Herausforderung, Konzepte zu entwickeln, mit deren Hilfe ein komplementärer Ausgleich dieser beiden Bereiche ermöglicht wird.
10. *Innovative Formen der Arbeitsorganisation*
    Der zunehmende organisationale und individuelle Flexibiliserungsdruck und die damit einhergehende Prozessbeschleunigung konstituieren einen fundamentalen Wandel der gesamten Arbeitswelt. Zur Stärkung der Innovationsfähigkeit bedarf es umfassender Anpassungsprozesse der Arbeitsorganisation, die nicht mehr allein auf die Reduktion von Kosten, sondern auf die Nutzung und Förderung von Humanressourcen ausgerichtet sind.
11. *Management der Ungewissheit*
    Individuen und Organisationen sind mit einer Umwelt konfrontiert, die sich mehr und mehr als unüberschaubar und unberechenbar darstellt. Insbesondere Innovationsprozesse erfordern Risikobereitschaft und ein Vertrauen in das Unplanbare.

Der Umgang mit Ungewissheit wird daher zu einer zentralen Fähigkeit, um unter flexiblen und dynamischen Bedingungen handlungs- und innovationsfähig zu bleiben.

## 4 Kurz gefasst

- Innovationen haben neben ökonomischen auch soziale und ökologische Nutzendimensionen.
- Um kontinuierlich Innovationen hervorbringen zu können, muss in Unternehmen eine ganzheitliche Innovationskultur geschaffen werden.
- 11 anwendungsorientierte Strategien helfen bei der Gestaltung der Innovationskultur.

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# Kybernetisches Innovationsmanagement für wissensintensive Organisationen

**Alan Hansen, Florian Welter, Anja Richert, Frank Hees und Sabina Jeschke**

**Zusammenfassung** Das Management von Innovationsprozessen erfolgt in wissensintensiven Organisationen häufig anhand linearer Modelle wie Stage-Gate-Ansätzen, die hohe Anforderungen an Planbarkeit stellen. Eine sinnvolle Erweiterung derartiger Ansätze bieten kybernetische Prinzipien, die ein iteratives Management von Innovationsprozessen unter Betrachtung großer Systemrahmen unterstützen. Entscheidungsträger sind in dieser Hinsicht verstärkt gefordert, ihre lineare Perspektive auf Innovationsprozesse durch die Analyse und Gestaltung innovationsförderlicher Rahmenbedingungen zu erweitern und damit die Ausschöpfung aller vorhandenen menschlichen, organisationalen und technischen Innovationspotenziale zu unterstützen. Ein praxiserprobtes Tool zur Diagnose und Gestaltung innovationsförderlicher Rahmenbedingungen bietet der Strategieplaner innoBOOST.

**Schlüsselwörter** Innovationsmanagement · Kybernetik · Innovationsfähigkeit · Organisationsentwicklung

## 1 Innovationsprozesse verlaufen nicht linear

Innovationen sind für den technologiebasierten Wirtschaftsstandort Deutschland von essentieller Bedeutung zur Sicherung der globalen Wettbewerbsfähigkeit. Die systematische Implementierung einer nachhaltigen Innovationsfähigkeit ist damit eine der zentralen Aufgaben von Entscheidungsträgern. Dies gilt insbesondere für wissensintensive Organisationen, die sich durch hohe Aufwendungen für Forschung- und Entwicklung sowie Technologien (z. B. Nano, Bio- oder Informationstechnologien) auszeichnen und dadurch über großes Potenzial für die Generierung von Produkt-, Prozess oder Dienstleistungsinnovationen verfügen. Maßnahmen zur Steigerung der Innovationsfähigkeit werden in der wirtschaftlichen Praxis jedoch häufig nur punktuell und intuitiv getroffen. Eine systematische Orientierung an passgenauen Strategien zur Etablierung einer nachhaltigen Innovationsfähigkeit

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**Abb. 1** Phasen des klassischen Stage-Gate-Modells nach Cooper

auf allen Organisationsebenen stellt bisher eher den Ausnahmefall dar. Innovationsaktivitäten werden vorwiegend durch eine vermeintlich spezialisierte Gruppe von Mitarbeitern in gekapselten Organisationseinheiten – in der Regel in Forschungs- und Entwicklungsabteilungen – initiiert und vorangetrieben [1].

Die Perspektive, die bei letzterem Vorgehen eingenommen wird, fokussiert insbesondere bei Produktinnovationen zumeist auf den Innovationsprozess, der alle Handlungen bezeichnet, die von der Idee für eine Innovation bis hin zu ihrer Durchsetzung am Markt in Innovationssystemen ablaufen. Dieser Prozess ist immer von Unsicherheit und einer nicht vollständig kontrollierbaren Dynamik geprägt, da Innovationen insbesondere durch das komplexe Wechselspiel sozialer Kommunikations- und Interaktionsprozesse zwischen menschlichen Akteuren entstehen und daher nur unvollständig plan- und steuerbar sind [2, 3]. Eine der zentralen Herausforderungen für Organisationen besteht demnach in der Bewältigung eines hohen Maßes an innovationsrelevanter Komplexität (z. B. Marktentwicklungen, Qualifikation der Mitarbeiter, Kommunikationstechnologien). In der Managementpraxis werden aus diesem Grund Innovationsprozesse häufig anhand von Phasenmodellen dargestellt, überwacht und bewertet [4]. Das bekannteste Modell stellt der sogenannte Stage-Gate-Ansatz dar, der auf die Arbeiten von Robert G. Cooper zurückgeht [5]. Dieses primär sequentiell ausgerichtete Modell gliedert einen Innovationsprozess in verschiedene Phasen und Gates, wobei letztere als Meilensteine und Entwicklungsindikatoren fungieren: Der Eintritt in die nächste Phase eines Innovationsprozesses ist nur möglich, wenn zuvor bestimmte (Qualitäts-)Kriterien erfüllt werden. Andernfalls ist auch ein Abbruch des Projektes denkbar. Klassischerweise werden die drei linear ablaufenden Hauptphasen in Idee, Akzeptanz und Realisierung unterteilt (vgl. Abb. 1).

Einen ähnlichen Ansatz verfolgt Winston Royce in der Informatik mit seinem Wasserfallmodell [6]. Darin stellt er den Prozess der Softwareentwicklung anhand von sieben aufeinanderfolgenden Phasen dar. Die im Wasserfallmodell postulierte Linearität und Sequentialität von Softwareentwicklungsprozessen erschwert jedoch die in der Praxis häufig notwendige Anpassung von Kundenanforderungen. In der Realität besitzen die verschiedenen Entwicklungsschritte demnach weniger sequentiellen als vielmehr komplexen und iterativen heterogenen Charakter. Aus diesem Grund wurde die sequentielle Grundausrichtung des Modells seit Beginn des 21. Jahrhunderts stufenweise durch neuere Ansätze erweitert, die auf agilen und zyklischen Prinzipien beruhen. Diese Prinzipien ermöglichen z. B. eine flexible Anpassung von Entwicklungsprozessen, z. B. infolge von veränderten Kundenanforderungen oder Marktbedingungen.

Diese agile Perspektive lässt sich auf das Management von Innovationsprozessen übertragen. So wurde das Stage-Gate Modell nach Cooper in den letzten Jahren ebenfalls durch das Einfügen paralleler und iterativer Abläufe modifiziert und damit stärker an den Bedingungen in der wirtschaftlichen Praxis ausgerichtet. Aktuelle Ansätze zeigen, neben einer linear-sequentiellen Grundstruktur, den Versuch der Integration parallel ablaufender Phasen eines Innovationsprozesses [7]. Diese erweiterte Perspektive korreliert mit einem potenziellen Lösungsansatz für die grundsätzlich erschwerte Planbarkeit von Innovationen, der die Implementierung kybernetischer Prinzipien vorsieht und damit eine ganzheitliche Organisationsbetrachtung ermöglicht [8].

## 2 Kybernetische Betrachtung von Innovationsprozessen

Ein Innovationssystem besteht zunächst aus Elementen (z. B. Menschen, Technologien, Regelungen, etc.), die Merkmale (Motivation, flexible IT-Strukturen, Fehlertoleranz, Gesundheit, Kreativität, etc.) besitzen und sich voneinander unterscheiden. Zwischen Elementen eines Systems bestehen Beziehungen, die ihrerseits Merkmale (z. B. Verstärkung, Hemmung, Korrelation, Blockierung) aufweisen und den Elementen eine vernetzte Form verleihen.

In diesem Sinne sind in einem System Elemente menschlicher, organisationaler und technischer Art vorhanden, die in ihrem Wechselspiel bestimmte Phänomene (Ideen, kreative Gedanken, Visionen, etc.) erzeugen, die nicht losgelöst voneinander zu beschreiben sind. Beispielhaft führt persönliche Interaktion in fachlich wie auch kulturell divers zusammengestellten Teams zur Generierung völlig neuartiger Produktideen, die nicht ausschließlich durch die Expertise aller einzelnen Teammitglieder zu erklären sind. In einem kybernetischen Verständnis wird diese Beobachtung mit dem Auftreten von Emergenz erklärt [9].

Eine kybernetische Betrachtung erlaubt wissensintensiver Organisationen u. a. die Modellierung von (System-)Merkmalen [10] über Ursache-Wirkungsbeziehungen. Hierfür bietet sich z. B. die Anwendung der Methodik System Dynamics an, mit deren Hilfe Wirkungsbeziehungen zwischen menschlichen, organisationalen und technischen Merkmalen einer Organisation qualitativ und quantitativ transparent gemacht Wirkungen dargestellt werden können [11]. Auf diese Weise leistet eine kybernetische Betrachtung einen Beitrag zum Umgang mit organisationsinterner Komplexität. Darüber hinaus wird der Messung und Bewertung von Merkmalen einer wissensintensiven Organisation große Bedeutung zu teil [12, 13], weil daraus resultierende Ergebnisse über Feedbackschleifen zurückgeführt werden können. Feedback als ein kybernetisches Kernprinzip bildet schließlich die Grundlage zu einer Anpassung von Systemkomplexität [14] durch das Management, was z. B. die Adaption von Organisationsstrukturen und Managementprozessen beinhaltet.

Hinsichtlich einer Erweiterung klassischer Stage-Gate-Ansätze eröffnet beispielsweise die Nutzung von kybernetischen Rückführungsschleifen von der Phase Realisierung in die Phase Idee, die Möglichkeit zu einer veränderten, optimierten Ideen-Phase (vgl. Abb. 2). So können Erfahrungen und Erkenntnisse am ersten Gate eines Produktinnovationsprozesses z. B. die Notwendigkeit aufzeigen, eine längere und/oder veränderte Ideen-Phase zu implementieren. Diese Notwendigkeit lässt sich

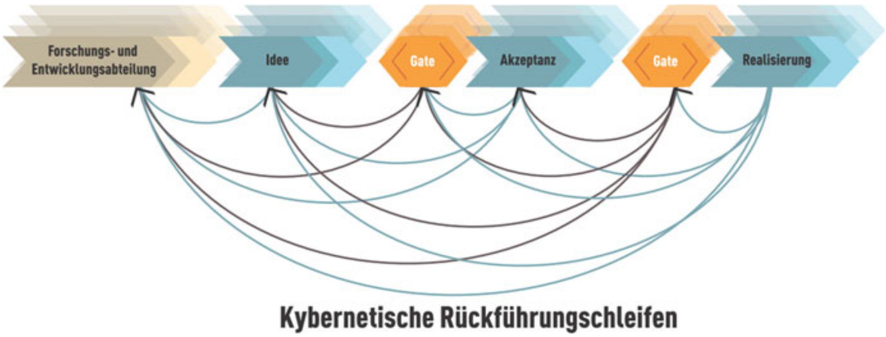


**Abb. 2** Modifizierung von Phasen des Innovationsprozessmanagements durch kybernetische Rückführung [3]

z. B. mit der Integration weiterer interdisziplinärer Experten (darunter Produzenten wie auch Konsumenten) erklären, die mit ihrem heterogenen Wissen in einem offenen Innovationsprozess zu einer kreativeren Ideenfindung beitragen. Daneben lassen sich nicht nur einzelne Prozessschritte, sondern auch „Gates" und dazugehörige Qualitätskriterien adaptieren.

Eine kybernetische Perspektive von Innovationsprozessen versetzt damit insbesondere Führungskräfte in die Lage, die Innovationsfähigkeit ihrer Organisation kontinuierlich aus einer Metaperspektive zu monitoren und bei Bedarf regelnd in Prozesse und Strukturen einzugreifen. Ein derartiges Vorgehen kann u. a. präventiv im Hinblick auf eine fehlerhafte Einschätzung von Kundenbedürfnissen oder der benötigten personellen und monetären Ressourcen wirken. Bei der Anwendung von klassischen oder erweiterten Stage-Gate-Modellen ist allerdings auch zu beachten, dass diese in erster Linie die Entwicklung inkrementeller Innovationen (z. B. die Weiterentwicklung von Modellreihen in der Automobilindustrie) unterstützen. Derartige Prozesse lassen sich eher standardisieren und steuern als solche im Kontext von radikalen Innovationen (z. B. Google Glasses), die sich durch disruptive, dynamische Prozesse auszeichnen und deshalb eine ganzheitliche organisationale Perspektive erfordern.

## 3 Innovationsförderliche Rahmenbedingungen als Perspektivenerweiterung

Die Isolation innovationsbezogener Aktivitäten in Forschungs- und Entwicklungsabteilungen hemmt die Ausschöpfung der in einer Organisation vorhandenen Innovationspotenziale, da möglicherweise relevante Akteure nur selektiv in Innovationsvorhaben integriert werden. Organisationen sind demnach gefordert, über das Management von Innovationsprozessen hinaus, ganzheitliche Rahmenbedingungen und damit eine Innovationskultur zu schaffen, die die Partizipation jedes Mitarbeiters strategisch fördert [15]. Denn: Viele Entscheidungsträger ignorieren die Tatsache, dass es nur schwer beleg- und messbare Zusammenhänge zwischen dem Input (z. B. Marktentwicklungen, Anregungen von Kunden), der aus der Umwelt (z. B. Konkurrenten, Markt, gesellschaftliche Einflüsse) in eine Organisation einfließt und dem Output (z. B. Innovationen), der an die Umwelt abgegeben wird, gibt. Die Entwicklung von Innovationen stellt demnach einen unsicheren, schwer kontrollierbaren sozialen Prozess dar, bei dem es in erster Linie darum geht, das Zusammenspiel aller innovationsrelevanten Merkmale systemisch zu stärken [16]. Die Innovationsfähigkeit einer Organisation bezeichnet in diesem Sinne bestimmte menschliche, organisationale und technische Voraussetzungen, die die kontinuierliche Erzeugung von Innovationen unterstützen. Folglich muss ein adäquates Innovationsmanagement als Enabler fungieren und, der systemischen Auffassung folgend, die Ideengenerierung motivieren, den Innovationsprozess begleiten und das Mitwirken aller faktisch und potenziell Beteiligten unterstützen. Das bedeutet im Umkehrschluss, dass Entscheidungsträger in wissensintensiven Organisationen gefordert sind, ihre häufig rein auf den Innovationsprozess gerichtete Perspektive zu erweitern und insbesondere die Rahmenbedingungen zur kontinuierlichen Entwicklung von Innovationen bewusster und zielgerichteter zu managen. Die klassischen Stage-Gate-Ansätze müssen damit um eine, die ganze Organisation umspannende, Ebene erweitert werden und menschliche, organisationale und technische Merkmale sowie Umweltbedingungen gleichberechtigt in das Innovationsmanagement einer Organisation einbeziehen (vgl. Abb. 3).

Ein Beispiel für ein innovationsförderliches Merkmal ist z. B. die Etablierung von Diversity Teams: Die Diversität von Abteilungen und Teams fördert aufgrund der vielfältigen Erfahrungen sowie persönlicher und fachlicher Hintergründe die Entwicklung und multiperspektivische Auseinandersetzung mit Ideen. Ein weiteres Beispiel für ein innovationsförderliches Merkmal ist die Akzeptanz für Veränderungen. Eine derartige Kultur zeichnet sich durch einen stetigen Abbau von Ängsten vor Neuerungen und Tendenzen am Festhalten von vermeintlich alt bewährten Prozessen und Strukturen aus. Die Etablierung derartiger Merkmale führt nicht nur dazu, dass mehr Ideen generiert werden können. Darüber hinaus wird der gesamte Innovationsprozess, unter Einbeziehung aller relevanten Akteure, kontinuierlich reflektiert und damit qualitativ verbessert.

## 4 Der Strategieplaner innoBOOST

Um Entscheidungsträgern ein praktikables Management-Tool zur Analyse und kontinuierlichen Verbesserung der organisationalen Innovationsfähigkeit zu bieten, wurde in Kooperation zwischen dem Institutscluster IMA/ZLW & IfU der RWTH Aachen mit der Nets'N'Clouds GmbH der webbasierte Strategieplaner innoBOOST entwickelt (www.innoboost.de) [17]. Das Management-Tool beinhaltet ein breites Repertoire an praxiserprobten Merkmalen, die die Innovationsfähigkeit einer Organisation steigern können.

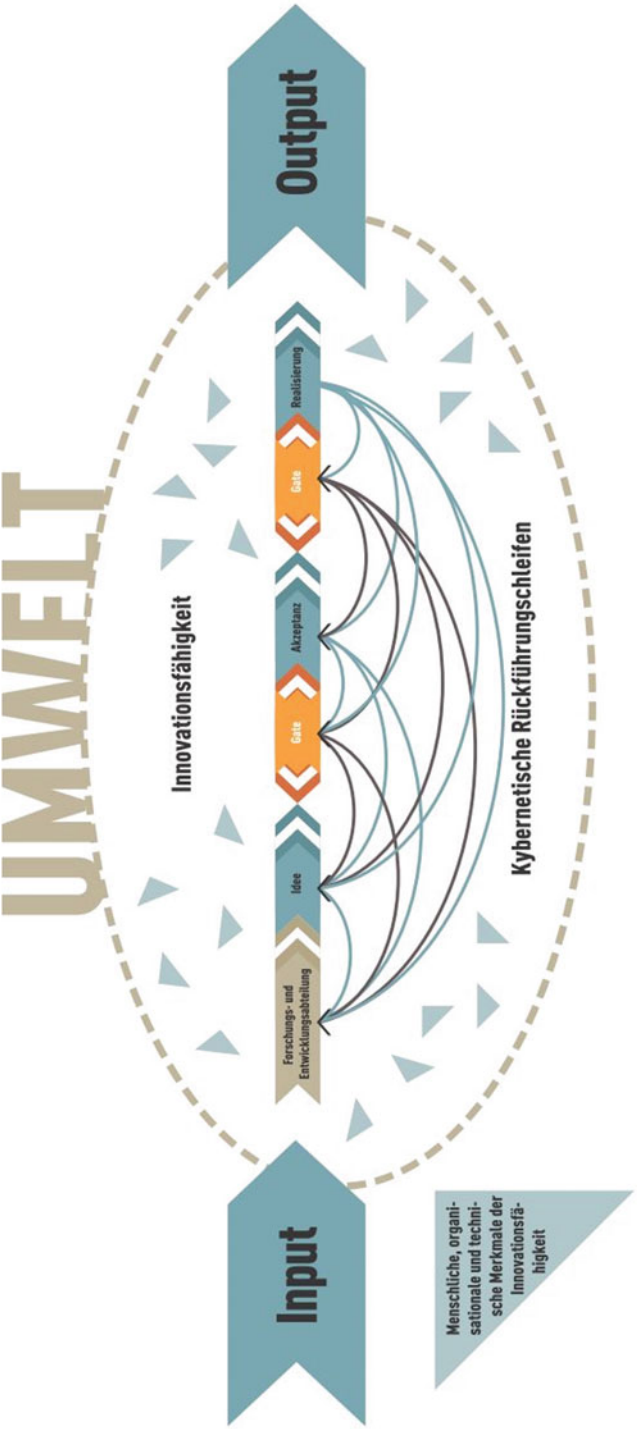


**Abb. 3** Wissensintensive Organisation als Innovationssystem

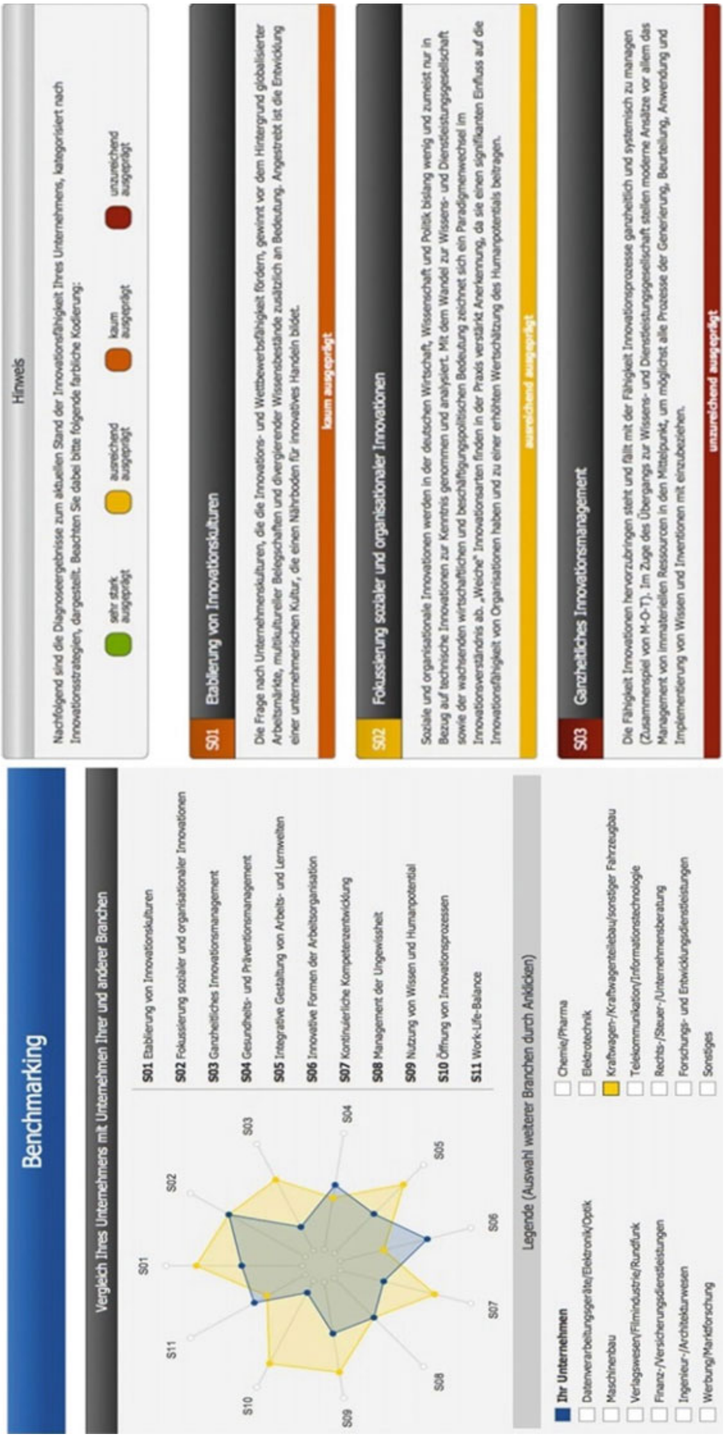


**Abb. 4** Screenshot des Strategieplaners innoBOOST

übergreifende Strategien werden aufgezeigt, die eine ganzheitliche Gestaltung innovationsförderlicher Rahmenbedingungen ermöglichen. Die Anwendung des Tools erlaubt ein Benchmarking (vgl. Abb. 4), das das kybernetische Prinzip der Kontrastierung von eigenen organisationalen Merkmalen mit denen von Wettbewerbern aufgreift. Durch einen Abgleich mit Organisationen aus verschiedenen Branchen werden einerseits eigene Stärken und Schwächen in Bezug auf die Entwicklung von Innovationen transparent gemacht und Entwicklungspotenziale gegenüber Wettbewerbern aufgezeigt. innoBOOST unterstützt die Generierung individualisierter Handlungsempfehlungen zur passgenauen Umsetzung von Innovationsstrategien und konkreten Maßnahmen zur Realisierung innovationsförderlicher Rahmenbedingungen.

Neben dem Fokus des vorliegenden Beitrags auf ein kybernetisches Innovationsmanagement, das die Innovationsfähigkeit und dazugehörigen Innovationsprozesse im Innern einer wissensintensiven Organisation behandelt, stellt die Einbeziehung eines externen Monitorings – im Sinne einer externen Erfassung, Analyse und Rückführung von Innovationsleistungen, die aus einer wissensintensiven Organisation hervorgehen – einen weiteren Schwerpunkt eines kybernetischen Innovationsmanagements dar [3]. Die Entwicklung eines integrierten, kybernetischen Innovationsmanagements, strebt demnach an, sowohl organisationsinterne als auch organisationsexterne Feedbackschleifen abzubilden, da hierdurch gleichzeitig das Management von Innovationsprozessen, des Innovationssystems wissensintensive Organisation und der Innovationsleistung als Output des Systems ermöglicht wird.

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# Partizipation und Führung – Grundpfeiler der Organisationsentwicklung aus systemischer Sicht

**Klaus Henning**

**Zusammenfassung** Selbständige Mitarbeiter und Mitarbeiterinnen brauchen mehr Führung. Bei unselbständigen sagt man als Chef einmal was zu tun ist und dann werden Anweisungen eben ausgeführt, ohne weiter nachzudenken. Da wir uns aber Mitarbeiter als Mitgestalter und Mit-Unternehmer der eigenen Organisation wünschen, müssen wir ihnen einerseits viel Selbständigkeit und Entfaltungsspielraum geben. Andererseits gehen Mitarbeiter dann mit Anweisungen des Chefs anders um. Sie denken darüber nach und haben schnell eigene, oft auch bessere Ideen. Und dann bin ich als Chef schon wieder gefragt, zu führen, und das viel öfter als vorher.

**Schlüsselwörter** Partizipation · Führung · Empowerment · OSTO Systemansatz · Kernprozesse

> Unternehmensführung ist nicht die Beschäftigung mit Gegenwartsproblemen, sondern die Gestaltung der Zukunft. (Daniel Goeudevert)
>
> Behandle die Menschen so, als wären sie, was sie sein sollten, und du hilfst ihnen zu werden, was sie sein können. (Johann Wolfgang von Goethe)

## 1 Vorbemerkung[1]

Viele meiner leitenden Mitarbeiter waren mir in den letzten 25 Jahren ein Vorbild für gelebte Führung durch partizipative Prozesse. Partizipation heißt nicht, dass alle bei allem mitreden dürfen! Es ist absolut notwendig immer wieder durch klare Ansagen die notwendige Richtung anzugeben. Dies ist manchmal auch notwendig, wenn die beteiligten Akteure nicht zu einer gemeinsamen Auffassung kommen. Dabei muss ich als Führungskraft aber auch bereit sein, mich vom Gegenteil überzeugen

[1] Die hier abgedruckte Version des Beitrags wurde dem Originalbeitrag gegenüber leicht abgeändert.

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zu lassen, aber niemals ohne handfeste Argumente. Oft ist auch ein tragfähiger Kompromiss wichtiger als die eigene Überzeugung. Aber erst, wenn Position und Gegenposition klar auf dem Tisch liegen.

Ich hatte in meinen Anfangsjahren als Institutsleiter (1985–2010) des Zentrum für Lern- und Wissensmanagement/Lehrstuhl Informationsmanagement im Maschinenbau einmal die Idee gehabt, die für das Institut zur Verfügung stehenden reservierten Parkplätze partizipativ in einem Beteiligungsprozess zu vergeben. Ein Kollege aus dem Leitungsteam stürmte daraufhin unangemeldet in mein Büro und sagte: „Klaus, wie kannst Du die Parkplatzverteilung zum Gegenstand eines partizipativen Prozesses machen?! Das musst Du als Chef entscheiden und damit Basta.“ Es hatte schon eine heftige Diskussion um dieses Thema gegeben und alle waren irgendwie sauer. In dieser Situation waren dann alle Beteiligten erleichtert, dass es eine Chefentscheidung gab. Übrigens haben wir die Parkplätze aufgeteilt zwischen der Führungsebene und den Mitarbeitern und Mitarbeiterinnen mit den geringsten Jahresgehältern.

Wenn man sich nicht vorher überlegt, wie man das „System“ der Zusammenarbeit der beteiligten Menschen gestaltet, bekommt man fast sicher später ein Problem. Das hatte ich bitter in einem Automatisierungsprojekt erfahren müssen, in dem wir die davon betroffenen Menschen einfach nicht einbezogen hatten. Führung alleine genügt nicht! Das lernte ich zum ersten Mal durch das damalige Programm „Mensch und Technik. Sozialverträgliche Technikgestaltung“ des Landes NRW, das durch Robert Sell in das Institut kam. Es erschloss sich mir die Welt der Gewerkschaften. Freunde, wie Udo Blum von der IG Metall, wurden Freunde des Hauses. Gemeinsam suchten wir nach Wegen, im BMBF einen Pfad alternativ zu CIM-Ansatz (Computer Integrated Manufactoring) zu finden. Wir nannten ihn HCIM – Human Computer Integrated Manufactoring. Prof. Peter Meyer-Dohm, damals Leiter Personalwesen bei Volkswagen, half uns dabei ganz maßgeblich. Die Saat ging auf u. a. in einer Dissertation „Beteiligungsqualifizierung zur Gestaltung von technischen und organisatorischen Innovationen“ [1]. Außerdem wurde Beteiligungsqualifizierung zu einem zentralen Bestandteil von unzähligen Projekten und hat weite Teile der weiteren Förderprogramme des BMBF geprägt. Wenn das Institut heute seit vier Jahren das gesamte Internationale Monitoring-Programm für das Forschungs- und Entwicklungsprogramm „Arbeiten, Lernen, Kompetenzen entwickeln Innovationsfähigkeit in einer modernen Arbeitswelt“ verantwortet und durchführt, dann wäre das ohne die frühen Initiativen von Robert Sell nicht denkbar gewesen. Ihm ging es immer um das Zusammenspiel von Partizipation und Führung. Auch mit mir als sein Chef.

Das Zusammenspiel von Partizipation und Führung habe ich eines Tages durch ebendiesen Robert Sell besonders kennengelernt. Er kam zu mir ins Büro – wieder immer ohne Anmeldung – und sagte: „Ich muss noch mal was Neues machen. Ich mache mich selbstständig.“ Mir blieb erst einmal die Spucke weg. Ich kannte ihn gut genug, um zu wissen, die Sache hat er schon entschieden. Auf mein Schweigen fuhr er fort: „Nur damit es klar ist: Ich will keinerlei Unterstützung weder ideell noch finanziell. Ich mache mich selbstständig.“ Was für ein beeindruckender Weg:

Ingenieurstudium, aktiver Gewerkschafter – und in der „zweiten" Lebenshälfte Unternehmer – und das bis heute. Und natürlich nicht nur in Aachen, sondern mit Ablegern in den neuen Bundesländern und in Tschechien.

Wie passt partizipative Führung und Führung partizipativer Prozesse zusammen. Dies ist nun mein Thema, das ich wissenschaftlich an dieser Stelle beleuchten möchte. Dabei stütze ich mich in Teilen auf die Dissertation von Eva Sanders [2], die in Ihrer Arbeit die verschiedenen Stränge von partizipativen und systemischen Ansätzen zusammengeführt hat.

## 2 Zu den Rahmenbedingungen

Zu Beginn des neuen Jahrtausends sieht sich unsere Gesellschaft mit veränderten Realitäten konfrontiert. Der strukturelle Wandel hat sich in Richtung einer Wissensgesellschaft fortgesetzt und prägt die neuen Rahmenbedingungen der (Arbeits-)Gesellschaft. Globalisierung und Dynamisierung von Märkten, der Wandel vom Anbieter- zum nachfrageorientierten Markt (Kundenmarkt) sowie die flächendeckende Ausbreitung und die rasant wachsenden Möglichkeiten neuer Informations- und Kommunikationsformen, allen voran des Internet mit seinen Möglichkeiten der sozialen Netzwerke, stellen neue Anforderungen an Unternehmen und Mitarbeiter[2].

Vor diesem Hintergrund ist seit Beginn der 90er Jahre in der betrieblichen Praxis ein Phänomen zu beobachten, das als „Partizipation & Empowerment" bezeichnet wird und seither viel Beachtung und Zuspruch findet. In erster Näherung kann das Phänomen von „Partizipation & Empowerment" (kurz: P&E) verstanden werden als die Frage nach Beteiligung und Befähigung im Unternehmen. P&E beschreibt die Übernahme und Übergabe von Verantwortung an Mitarbeiter aller betrieblicher Hierarchieebenen. Als kombinierter Begriff greift P&E dabei auf die Strategien und Ziele der Partizipation auf der einen Seite und des Empowerment auf der anderen Seite zurück [3]. Im Zuge dieser Entwicklungen wird die Erwerbsarbeit durch Aspekte des unternehmerischen Handelns stärker bereichert. Das Schlagwort vom Mikrounternehmer im Unternehmen, der im Sinne des Unternehmens denkt und handelt, beschreibt diesen [4].

> In einer solchen Welt wachsender Turbulenzen erleben wir ein Wechselbad widersprüchlicher Entwicklungen positiver und negativer Art, die sich zunehmend häufiger plötzlich ablösen. Die Chancen und Risiken steigen ständig. ([5], S. 13)

Diese Entwicklungen fordern unternehmerisch zu denken und Verantwortung zu übernehmen. Dies wird zunehmend anspruchsvoller, da in einer Welt wachsender Turbulenzen (vgl. Abb. 1) in immer kürzeren Abständen Neuorientierungen geleistet werden müssen.

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[2] Im Folgenden wird aus Gründen der Vereinfachung die maskuline Form verwendet, gemeint sind Mitarbeiter beider Geschlechter.

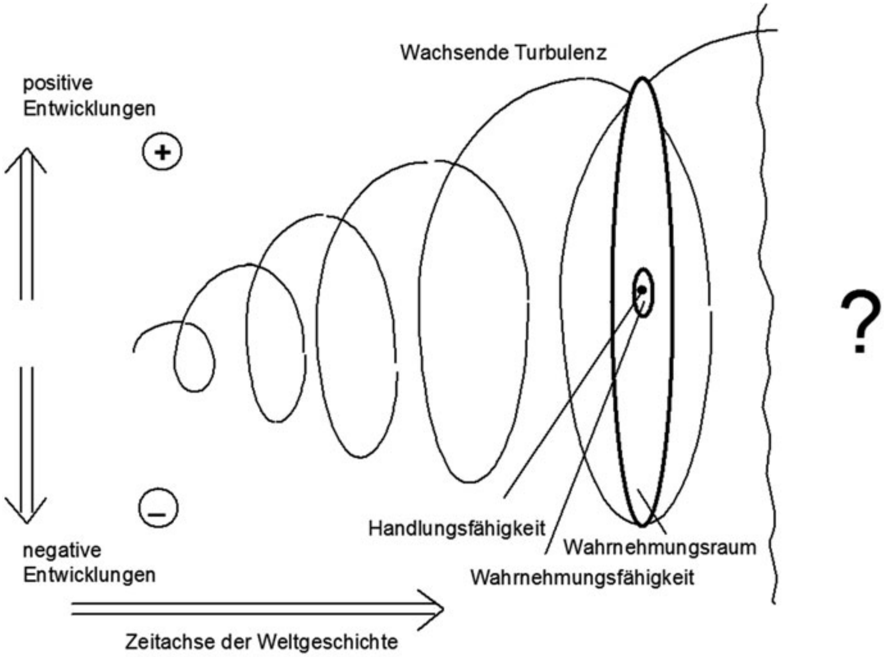


**Abb. 1** Eine Welt wachsender Turbulenzen [5]

Die Menge an Informationen, die erforderlich ist, um komplexe Situationen vollständig erfassen zu können (der Wahrnehmungsraum), übersteigt jedoch die Möglichkeiten unserer Wahrnehmungsfähigkeit. Diese Wahrnehmungen wiederum übertreffen unsere tatsächliche Handlungsfähigkeit um ein Weites. Daraus ergibt sich, dass mit Zunahme der Turbulenz die Diskrepanz zwischen Wahrnehmungsraum, Wahrnehmungsfähigkeit und Handlungsfähigkeit ständig zunimmt.

Es liegt auf der Hand, dass diese zunehmenden Anforderungen und Diskrepanzen, mit denen sich neben Führungskräften auch immer mehr abhängig Beschäftigte im Erwerbsleben konfrontiert sehen, auf den ersten Blick zunächst einmal eine Gefahr für die Work Life Balance darstellen. In der Strategie von P&E ist eine Chance für die Work Life Balance zu sehen, obwohl das P&E-Konzept gerade darauf abzielt, Mitarbeitern noch mehr Verantwortung zu übertragen [3].

## 3 Worum geht es bei „Partizipation & Empowerment"

### *3.1 Partizipation*

Partizipation ist zunächst als „Entscheidungsbeteiligung" [6] bzw. konkreter als „aktive Mitwirkung der Betroffenen an allen Problemen, die ihre betriebliche Arbeit betreffen" zu definieren ([7], S. 19) [8]. In diesem Feld hat Deutschland mit seiner starken Mitbestimmungstradition vor allem hinsichtlich institutionalisierter Formen von Mitarbeiterbeteiligung (Betriebsräte) Zeichen gesetzt. Im Rahmen des staatlichen Forschungs- und Aktionsprogramms „Humanisierung des Arbeitslebens" (HdA) gewann in den 70er und 80er Jahren die politische und wissenschaftliche Debatte um Beteiligung von Mitarbeitern in Deutschland an Dynamik. Beteiligung wurde hier klar als Instrument zur Humanisierung des Arbeitslebens und der persönlichkeitsförderlichen Arbeitsgestaltung im Dienste der Mitarbeiter verstanden und nicht als Rationalisierungsinstrument im Dienste des Managements. Dies änderte sich mit der Verbreitung der Lean-Management-Konzepte: Hier war Beteiligung, ausgehend vom Management, Mittel zum Zweck, um Innovationskraft, Effektivität und Effizienz des Unternehmens zu steigern [9]. Persönlichkeitsförderliche Zielsetzungen erhielten eine untergeordnete Bedeutung.

Partizipation von Beschäftigten an Veränderungs-, Entwicklungs- und Verbesserungsprozessen stellt einen grundlegenden Unterschied zum Taylorismus (Scientific Management) dar und „ermöglicht besseres Verständnis, Identifikation und Zugehörigkeit" [7]. In der Literatur wird Partizipation in der Regel mit Beteiligung gleichgesetzt. Gemeint ist damit jedoch nicht nur die finanzielle Beteiligung, sondern die Beteiligung der Mitarbeiter an allen betrieblichen Prozessen.

Führungskräfte sehen in Partizipationsprozessen häufig nur eine Rationalisierungsressource, einen geeigneten Weg zur optimalen Nutzung des Erfahrungswissens und des Kreativitätspotentials der Beschäftigten. Beschäftigtenpartizipation ist gerade aus Sicht partizipativer Managementkonzepte nur in dem Maße „gerechtfertigt", wie sie zur Produktionsverbesserung in dem jeweiligen Unternehmen beiträgt [10]. Damit treten die ursprünglichen Ziele der Mitbestimmungs-/Beteiligungsdiskussion – eine humanere, bedürfnisorientierte Gestaltung der Arbeit – in den Hintergrund. Dies betrifft in erster Linie die eher „schwächeren", indirekten Formen der Partizipation.

## *3.2 Empowerment*

Beim Konzept des aus den USA stammenden Empowerments sollen „brachliegende" Potentiale und Fähigkeiten der Mitarbeiter zum Nutzen des Unternehmens erschlossen werden. Im Vordergrund steht dabei das Ziel, eine Erhöhung der Kundenzufriedenheit über die Beteiligung der Mitarbeiter zu erreichen [11]. Nach Ginnodo [12] kann Empowerment stärker als das Instrument, Partizipation als originäres Managementkonzept begriffen werden: In empowerten Unternehmen lösen Arbeitnehmer und Führungskräfte Probleme und treffen Entscheidungen, die traditionell höheren Managementebenen vorbehalten waren. Es findet eine Delegation von Verantwortung, Entscheidungs- und Handlungsspielräumen statt. Dieses seit den 90er Jahren existierende Managementkonzept ist vom „Involvement" der 80er Jahre (Beteiligung an Problemlösung und an Entscheidungsfindung, z. B. über Qualitätszirkel oder individuelles job enrichment) und vom traditionellen Management abzugrenzen, in dem die Führungskräfte einen großen Teil der anfallenden Probleme lösen und Entscheidungen weitgehend allein fällen [3].

Empowerment ist als ganzheitliche Anwendung ein Element prozessorientierter Organisationsgestaltung [11]. Als Teil des Business Reenginieering [13, 14] ist es ein Teil der Prozess-Idee, der kundenorientierten Rundumbearbeitung in Prozessen:

> Das Prozess-Team soll sich möglichst im Wege der Selbstabstimmung koordinieren. Dadurch werden Vorgesetzte von ihren Koordinationsaufgaben entlastet. Ihre Leistungsspanne kann größer und die Hierarchie flacher werden. Gleichzeitig erhalten die Mitarbeiterinnen und Mitarbeiter die Entscheidungsbefugnisse, die sie benötigen, um die Kunden im Rahmen der jeweiligen Prozessvariante zu befriedigen (Empowerment). Es ist Schluss mit Sätzen wie ‚dafür bin ich nicht zuständig' (horizontale Schnittstelle) und ‚das darf ich nicht entscheiden' (vertikale Schnittstelle) ([13], S. 32 f.).

Während die Mitglieder der Geschäftsleitung Empowerment als Konzept der Grundidee nach zumeist befürworten, wird die Umsetzung oft auf subtile Art verhindert. Auch Mitarbeiter betrachten Empowerment häufig mit gemischten Gefühlen: Zwar begrüßen sie es, über mehr Verantwortung und Entscheidungsfreiheit zu verfügen, lehnen aber die persönliche Rechenschaftspflicht ab. Für die Mitarbeiter ist es kaum möglich, sich eigenverantwortlich zu engagieren, wenn sie sich „von oben" kontrolliert fühlen [3].

Zwar spielen in der Diskussion um Empowerment Eckpunkte wie Motivation, Commitment und Entwicklung von Mitarbeitern eine Rolle. Es kann zusammengefasst werden, dass Empowerment als Führungsinstrument einzuordnen ist, das nicht primär darauf abzielt, Mitarbeiter an der Findung und Formulierung etwa von Unternehmenszielen zu beteiligen. Vielmehr werden sie an der Entscheidungsfindung auf operativer Ebene beteiligt, damit Unternehmensziele erreicht werden [15]. Nach Ginnodo [12] kann Empowerment daher stärker als das Instrument begriffen werden, Partizipation – und zwar besonders Partizipation umgesetzt mit einer Social-Values-Strategie oder umgesetzt als authentische Partizipation – dagegen als originäres Managementkonzept.

## 4 Das integrierte Konzept von Partizipation & Empowerment

Insgesamt gibt es heute ein breites Spektrum neuer Beteiligungsformen. Unterschiede zeigen sich dabei hauptsächlich bezüglich des Stellenwerts, den die Beschäftigten-Beteiligung im Gesamtkonzept der Reorganisation besitzt.

Die abhängig Beschäftigten wirken entsprechend ihrer Interessen aktiv an der Gestaltung ihrer Arbeitsbedingungen mit und sind an der Wissensbildung einer hierarchisch höheren Ebene beteiligt. Das heißt, die Untergebenen und ihre Vorgesetzten treffen anfallende Entscheidungen gemeinsam. Wichtig ist dabei, dass die Partizipienten Einfluss auf den Verlauf und den Ausgang von Entscheidungsprozessen nehmen können [13].

Auch wenn der Unterschied zwischen beiden Konzepten Partizipation und Empowerment zugespitzt herausgearbeitet werden kann, zeigt sich in der praktischen

Umsetzung, dass beide Konzepte sich stark aufeinander zu bewegen und die Umsetzung des Konzepts P&E offenbar starke Synergien für die betriebliche Praxis hervorbringt. Für die Entstehung des in der Praxis beobachteten Phänomens von *gelebtem P&E* scheinen zwei Prozesse zentral zu sein:

- *Mitarbeiter*, die im Kontext ihrer Arbeit eigenverantwortlich handeln und Verantwortung übernehmen *sollen*, müssen dies nicht nur *können* – wie es das Empowerment zu Recht bereits erkannt und umgesetzt hat – sondern ebenso *dürfen* und *wollen*. Besonders auf den Aspekt der *Motivation* zur Eigenverantwortung ist die Empowermentdiskussion bisher wenig eingegangen, zumindest was die um ein Vielfaches größeren Anreize zur Verantwortungsübernahme angeht, wenn Mitarbeiter nicht nur an der *Umsetzung* von Zielen beteiligt werden, sondern bereits an der *Formulierung* von Zielen [2].
- Auf Seiten der *Führungskräfte* ergeben sich aus diesem Prozess tiefgreifende neue Anforderungen. Diese beziehen sich nicht nur auf den Umgang mit den direkt zugeordneten Mitarbeitern, sondern ebenso auf das Selbstverständnis der eigenen Führungsrolle und bleiben auch für die Gestaltung der gesamten Organisation nicht ohne Konsequenzen, denkt man etwa an Fragen wie die Informationspolitik eines Unternehmens, Machtstrukturen, (monetäre) Anreizsystem u. m. Aus dem Empowerment als einem „einseitigen“ Führungsinstrument ist in der Praxis also de facto ein wechselseitiger Prozess zwischen Mitarbeitern und Führungskräften geworden.

Vor dem Hintergrund der so geführten Diskussion von Partizipation und Empowerment sowie der Beobachtung des Phänomens von P&E in der Praxis erscheint eine begriffliche Neubestimmung notwendig, die alte und neue Beiträge zu diesem Themenkomplex aufgreift und sie in den Kontext aktueller Veränderungsprozesse stellt. Danach sind nach unserem Verständnis unter den Bausteinen von P&E – die zu einem geschlossenen Konzept ausgebaut werden sollen – alle Maßnahmen in Unternehmen zu verstehen, die auf die Übernahme und Übergabe von Verantwortung auf allen Ebenen von Mitarbeitern zielen [16]. Die sich im Projektverlauf ergebenden Anforderungen an Führungskräfte und Mitarbeiter sind in Abb. 2 dargestellt.

P&E beinhaltet aus der Personal- und Organisationsentwicklung, die selbstständiges und eigenverantwortliches Handeln aller Mitarbeiter fördern. Dabei sind verschiedene Akteure [17] zu unterscheiden: So zielen P&E-Maßnahmen seitens der Mitarbeiter auf die Übernahme von Verantwortung. Parallel dazu müssen Führungskräfte lernen und in die Lage versetzt werden, Prozessverantwortung abzugeben. Letztlich findet P&E natürlich auch auf organisationaler Ebene statt, in Form des kulturellen Wandels zu einer organisatorischen Einheit, in dessen Rahmen die Organisationsmitglieder lernen, ständig zu Prozessen in der Organisation beizutragen.

Maßnahmen innerhalb von P&E-Konzepten dienen zum Aufbau eines P&E-Potentials im Unternehmen. Es geht darum, Mitarbeiter mit Kompetenzen auszustatten, damit sie diese Prozessverantwortung auch übernehmen können (*Können*), sie zu motivieren, dies zu tun (*Wollen*) und adäquate Strukturen mit Dispositionsspielräumen zu schaffen, die Prozessverantwortung ermöglich (*Dürfen*) und


**Abb. 2** Arbeitsdefinition P&E [16]

notwendig machen (*Sollen*). Die Ausprägung an P&E in einem Unternehmen entspricht dann der Reichweite der übertragenen Prozessverantwortung und dem abgerufenen P&E-Potential [3].

## 5 Kernprozesse des OSTO-Ansatz zur Integration von Partizipation und Empowerment

Einen anderen Zugang, um die Besonderheiten des Partizipationsansatzes hervorzuheben, stellt die Projektion der Grundideen des Partizipationsansatzes auf die Transformationsprozesse im Sinne des OSTO-System-Ansatzes dar [3, 18].

Der OSTO-System-Ansatz zielt auf die Beschreibung und Gestaltung von Organisationen ab, die darin als Offene Sozio-Technische Oekonomische (OSTO) Systeme betrachtet werden. Konkret soll die innerhalb dieses Ansatzes vorgeschlagene Betrachtung von *Prozessen* in Organisationen zur Einordnung des P&E-Konzepts herangezogen werden.

Im Sinne des OSTO-Ansatzes sind dabei unter dem Begriff „Kernprozesse" bestimmte Transformationsprozesse im Unternehmen zu verstehen. Kernprozesse zeichnen sich durch ihre Relevanz für die Erreichung der Systemergebnisse aus, die dem Grund für die Existenz der Organisation und damit den Kundenbedürfnissen entsprechen [5].

Während z. B. die Ansätze der „Lean-Familie" die Markt und Konkurrenzfähigkeit der Organisation primär dadurch zu steigern versuchen, dass die Aufgaben-Kernprozesse optimiert werden, verliert der Ansatz von P&E weder den individuellen

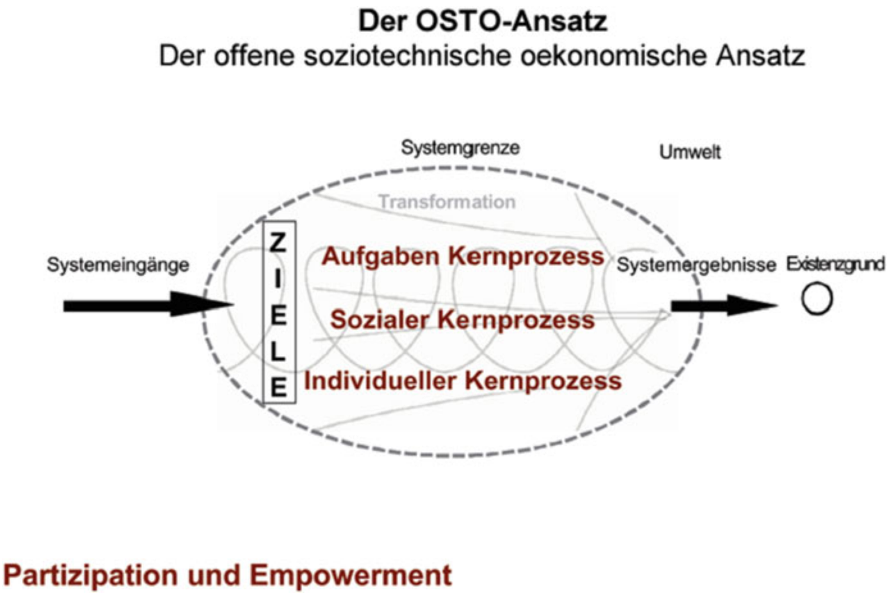


**Abb. 3** Partizipation & Empowerment als Strategie zur Konzentration auf die Kernprozesse [5]

noch den sozialen Kernprozess aus den Augen. Diese Kernprozesse sind im Sinne der systemischen OSTO-Idee als komplementär und unverzichtbar anzusehen. Diese effektive und gleichzeitig umsichtige, systemisch-ganzheitliche Betrachtung und Gestaltung der (Transformations-)Prozesse in der Organisation sind, so zeigen Praxisbeobachtungen von P&E in Unternehmen, auf ein ausgewogenes „Kräfteverhältnis" zurückzuführen. Diese Balance wird durch einen konstruktiven Aushandlungsprozess zwischen partizipierenden und empowerten/empowernden Mitarbeitern und Führungskräften vor dem Hintergrund eines gemeinsamen Nenners hinsichtlich individueller und Gesamtinteressen möglich. Die folgende Abb. 3 zeichnet diese Idee der Konzentration auf die Kernprozesse einer Organisation nach [3].

Die positiven Effekte dieser im Zuge von P&E erworbenen Bewältigungsstrategien für Lebensqualität und Work Life Balance liegen auf der Hand: Anforderungen und Ressourcen halten sich die Waage. So wird vermieden, dass trotz der aufgrund zunehmender Dynamik und Komplexität ansteigenden Belastung die wahrgenommene Beanspruchung im Arbeitskontext über ein „gesundes Maß" hinauswächst.

## 6 Partizipation und Führung als Grundpfeiler der Organisationsentwicklung

Eine der Rahmenbedingungen, die die P&E beeinflussen, bzw. durch die P&E beeinflusst werden, ist die Führung. Nach Weinert [15] stellt „Führung“: „Einen zwischenpersönlichen Einfluss- und Interaktionsprozess dar, eine Beeinflussung von Geführten, die neben den Qualitäten des Führers gewisse Situationsvariablen (wie Macht und Annahme der Führungsperson durch die Geführten und den dazu passenden Führungsstil) voraussetzt“.

Nach der oben dargestellten Definition beschreibt P&E die übergabe und Übernahme von Prozessverantwortung durch Mitarbeiter aller Hierachieebenen. Eine wichtige Rolle spielen dabei die Aspekte *Können*, *Dürfen*, *Sollen* und *Wollen*.

Innerhalb der Führungsebene eines Unternehmens muss der P&E-Ansatz akzeptiert werden, bevor es zu einer Verantwortungsübergabe an die Mitarbeiter kommen kann. Dadurch gestalten Führungskräfte die Rahmenbedingungen für P&E, diese werden gefestigt durch Vorgaben und das Verhalten der Führungskräfte. Das mehrdimensionale Konzept der Führung zeichnet sich (ohne Anspruch auf Vollständigkeit zu erheben) durch unterschiedliche Facetten aus wie Führungsstil und -verhalten, Verschiedenartigkeit von Führungsaufgaben, Führungspersönlichkeiten und Führungsverständnis (beispielsweise im Sinne von Coaching). Es umfasst weiterhin die faktischen Merkmale der Führungsposition im Sinne von Sanktionsmaßnahmen oder rechtlicher Haftbarkeit, die Gestaltung von Kultur, Struktur und Prozessen sowie die Beziehung zu Macht [19].

Bei dem Begriff Partizipation, wie oben beschrieben, handelt es sich um betriebliche Mitverantwortung und Mitgestaltung, um die Zusammenführung von Handlungsvollmacht und Verantwortung und damit um die Delegation von unternehmerischem Risiko. Die P&E-Instrumente und -Maßnahmen unterstützen die strategische Erneuerung des Führungsverständnisses. Auf der Unternehmerseite geht es um „Involvement“, das heißt Führungskräfte müssen sich wirklich „kümmern“ und Engagement zeigen, „empowered“ zu führen. Das Empowerment von Führungskräften ist ein strategischer Engpass. Daher ist zu beachten: Eigenständige Mitarbeiter brauchen mehr und „andere“ Führung, was aber nicht heißt, dass die P&E die „Abschaffung“ von Hierarchien und Macht bedeutet.

Im Rahmen partizipativer Führung kommt dem Vertrauen der Beschäftigten zu ihrem Betrieb und in die Betriebsführung eine zentrale Rolle zu. Beschäftigte benötigen die Sicherheit, dass ihr persönlicher Einsatz in Gestaltungsprozessen ernsthaft behandelt wird und nicht zu ihrem Nachteil erfolgt. Die Herstellung einer Vertrauenskultur im Unternehmen ist eine zentrale Aufgabe, die der Unternehmensführung zukommt. Wie immer Partizipationsprozesse organisiert werden: Die Unternehmensführung ist an ihnen beteiligt. Partizipation benötigt Informationen, Kommunikation, Entscheidungsfindung usw., welche ohne Führung nicht durchgeführt werden können – in vielen Fällen von Führung angestoßen werden müssen. Hierauf muss die bestehende Informations- und Kommunikations-“Politik“ achten, da partizipative Information und Kommunikation u. a. entscheidend an das Kriterium gebunden sind, dass sie den Beschäftigten eine selbstständige Entscheidung zu den anstehenden Sachfragen ermöglichen muss.

## 7 Zusammenfassung

Partizipative System- und Prozessgestaltung – ein Muss für Organisationen, die innovationsfähig sein wollen. Es geht dabei nicht einfach um Mitbestimmung durch die Mitarbeiter, sondern um Mitgestaltung. Es geht darum Mitarbeiter zu befähigen und die dafür notwendigen Rahmenbedingungen zu gestalten, dass sie wirklich mitzugestalten können und wollen. Manchmal degeneriert Partizipation auch zu einer „Pseudoveranstaltung" vor allem, wenn es nur darum geht die Akzeptanz für etwas zu erzeugen, was so wie so schon klar ist. Es geht also in einer innovationsfähigen Organisation um Partizipation im Sinne echter Mitgestaltung und Mitverantwortung – also um den Raum für eine Organisationentwicklung „von unten nach oben" entsteht. Wie oft hat sich bei diesem Weg herausgestellt, dass Führungskräfte die Potentiale ihrer Mitarbeiter nicht erkannt hatten oder nicht erkennen wollten.

Die Führung unselbständiger Mitarbeiter ist relativ einfach. Man gibt die Anweisung und – wenn es gut läuft – läuft es, ohne dass man als Führungskraft viel tun muss. Selbstständige Mitarbeiter brauchen eine andere Führung, denn selbstständige Mitarbeiter haben ja auch ständig neue Ideen! Da muss ich als Führungskraft dauernd umdenken und neu denken, anders handeln, Entscheidungen u. U. zurücknehmen und immer wieder neu Freiräume gewähren, immer wieder neu delegieren, immer wieder neu vertrauen. Das ist für eine Führungskraft anstrengend und erfordert sehr viel „involvement", d. h. sehr viel Investion in die Gestaltung der individuellen und der sozialen Kernprozesse eines Unternehmens. Dabei lerne ich als Führungskraft Komplexität und Dynamik einer Organisation zuzulassen und auch auszuhalten, nicht immer nach den schnellen und einfachen Lösungen zu suchen, sondern nach Lösungen, die die Komplexität und Dynamik der Freiräume nicht zerstören, sondern fördern. Daraus entstehen dann oft kleine Lösungen mit einer sehr großen Wirkung in die gewünschte Richtung. Und wenn man es gut macht, dann entstehen dabei nicht so viele unerwünschte Nebenwirkungen [20].

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# Industrie 4.0 als Treiber der demografischen Chancen

**Sabina Jeschke, René Vossen, Ingo Leisten, Florian Welter, Stella Fleischer und Thomas Thiele**

**Zusammenfassung** Anders als oftmals „pessimistisch" geprägte Darstellungen es erwarten lassen, birgt der demografische Wandel vielfältige Chancen und Möglichkeiten im Hinblick auf Innovationen in Unternehmen und Gesellschaft. Die Forschung konzentriert sich dabei vor allem auf die Entwicklung von Konzepten zur Unternehmens- und Arbeitsorganisation einerseits und zur Nutzung von veränderten Erwerbsbiografien andererseits. Eine ergänzende Perspektive dieser Handlungsfelder liegt in sich verändernden technischen Möglichkeiten und Bedingungen, die als Treiber der demografischen Chancen sowohl für den industriellen Sektor als auch für den Dienstleistungsbereich fungieren können. Diese Möglichkeiten und Bedingungen werden im folgenden Beitrag vor dem Hintergrund des Zukunftskonzepts Industrie 4.0 diskutiert und hinsichtlich ihrer Implikationen für die zukünftige Unternehmens- und Arbeitsorganisation erörtert.

**Schlüsselwörter** Industrie 4.0 · Demografischer Wandel · Demografie

## 1 Einleitung[1]

Vom demografischen Wandel zu sprechen bedeutet häufig, ihn hinsichtlich seiner möglichen Auswirkungen auf und abschätzbaren Belastungen für die sozialen Sicherungssysteme, insbesondere die Rentensysteme, zu hinterfragen ([1], S. 24). Erst in jüngerer Zeit wird in diesem Zusammenhang auch dem Beschäftigungssystem und der Gewährleistung individueller Beschäftigung als den wichtigsten Elementen

[1] Im Sprachstil dieses Beitrags sollen sich Männer und Frauen ausdrücklich gleichermaßen repräsentiert fühlen. Allein aus Gründen der besseren Lesbarkeit wird im Folgenden die maskuline Form (z. B. Mitarbeiter) verwendet.

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sozialer Sicherung mehr Beachtung geschenkt. Dass diese Aspekte aus ihrem lang anhaltenden Dornröschenschlaf allmählich erwachen bzw. erweckt werden, ist nicht nur sinnvoll, sondern auch unabdinglich, verweisen sie doch auf ein Erwerbstätigenpotenzial, das wertvolle, über die Wertschöpfungskette hinausgehende Zugewinne bereithält.

Politisch und juristisch sind mit der Verlängerung der Lebensarbeitszeit und der deutlichen Einschränkung der Möglichkeiten der Frühverrentung bereits Weichen gestellt worden, die die vor- und frühzeitige Ausgliederung bzw. das vor- und frühzeitige Austreten älterer Beschäftigter verhindern und so betriebliches Know-how längerfristig binden sollen ([2], S. 20). In der Tat scheint es zentral, mithilfe politischer und juristischer Instrumente das Leck zu schließen, das die große Generation der Babyboomer mit ihrem alsbaldigen Aufschließen zu den höheren Jahrgängen hinterlassen wird, denn mit dem Rückgang und der Alterung des Erwerbspotenzials sind enorme Herausforderungen für Wirtschaft und Gesellschaft verbunden, die sich auf anderem Wege nicht erfolgreich bearbeiten lassen ([1], S. 35; [3], S. 139).

Zu diesen Herausforderungen zählt auch die Frage, wie Transfer und Sicherung des in seiner Bedeutung nicht zu unterschätzenden Fachwissens sowie des impliziten und expliziten Erfahrungswissens Älterer gewährleistet werden können ([4], S. 121). Dies gilt vor allem für das Erfahrungswissen, das aufgrund seiner gleichermaßen rational-logischen wie intuitiv-gefühlsmäßigen Konzeption (vgl. [4], S. 121) gesellschaftlich als Kulturwissen und betrieblich als Fachwissen konserviert und transportiert werden muss. Dies sind nur einige der Stellschrauben, an denen gedreht werden kann, wenn es gilt, die Herausforderungen demografischer Veränderungen als Chance für Veränderungspotenzial zu nutzen.

Für Deutschland sind zwei demografische Charakteristika kennzeichnend: Zum einen ist der Prozess des demografischen Wandels hier im Vergleich zu vielen anderen Industrienationen weiter fortgeschritten, zum anderen wird – so stark wie in keiner anderen westlichen Industrienation – die Wirtschaftsleistung des Landes von der Produktion von Waren und Gütern getragen ([5], S. 1; [6]). Der weit fortgeschrittene demografische Wandel hält dabei ein Veränderungspotenzial für sämtliche gesellschaftlichen Bereiche bereit und flankiert individuell wie gesellschaftlich die Organisation von Leben und Lernen, von Arbeit und Gesundheit gleichermaßen ([7], S. 18). Für den Aspekt der Wirtschaftsleistung ist es unabdinglich, diese Veränderungspotenziale zu erkennen, aufzunehmen und in planvolle und gezielte Produktions- und Produktivitätsentwicklungskonzepte und -prozesse zu übersetzen. Die Gerontologisierung und numerische Regression der Gesellschaft ebenso wie der Fachkräftemangel erzeugen einen spürbaren Bedarf an assistierenden und (teil)automatisierten Maschinen und Systemen, die leistungsveränderte und altersdiverse Mitarbeiter befähigen, optimale Produkt- und Prozessergebnisse in hoher Qualität und Produktivität zu generieren.

Um die Wettbewerbs- und Innovationsfähigkeit Deutschlands weiterhin und langfristig nicht nur zu sichern, sondern auszubauen, müssen demografische Entwicklungen daher mit technischen Fortschritten verbunden und zu neuen Modellen und Konzepten der gezielten Nachfrage nach Arbeitskräften einerseits und der intelligenten Organisation von Produktionsmitteln sowie der Entwicklung von Produkt- und Produktionssystemen andererseits synthetisiert werden. Ein Zukunftskonzept dafür bietet die Industrie 4.0. Ein Ziel auf diesem Weg sollte die optimale Gestaltung von technischen und sozialen Innovationsprozessen ([8], S. 113) sowie der Interdependenzen zwischen diesen Prozessen sein. Die integrierte Betrachtung, die gesellschaftlichen und insbesondere demografischen Entwicklungen dasselbe Maß an Aufmerksamkeit schenkt wie technologischen – und sie zudem als Innovationschance betrachtet –, ist dabei die Voraussetzung für eine zukunftsorientierte und nachhaltige Wettbewerbsfähigkeit und Produktivität Deutschlands.

## 2 Chancen des demografischen Wandels im Kontext der Arbeitswelt

Der demografische Wandel stellt die Gesellschaft vor vielfältige Herausforderungen und Chancen im wirtschaftlichen, gesellschaftlichen und vor allem unternehmerischen Rahmen [9]. Das Motto „Wir leben länger. Wir werden weniger. Wir werden vielfältiger" [10] zeigt die drei übergeordneten Handlungsfelder einer „älteren Erwerbsbevölkerung", einer „Verkleinerung des Arbeitsangebotes" ([11], S. 114) sowie einer zunehmenden migrationsbedingten Vielfalt der Gesellschaft auf. Trends wie die Globalisierung und eine beschleunigte und wissensintensivere Arbeitswelt machen es erforderlich, Maßnahmen zur Erhaltung des Arbeits- und Produktivitätsstandes zu treffen sowie Maßnahmen zur Schaffung einer erhöhten Innovationskultur in der Arbeitswelt einzuführen ([12], S. 2). Diese kann nicht als unveränderliches Konstrukt betrachtet werden, sondern ist als „komplexes Zusammenspiel unterschiedlicher Akteure" ([13], S. 38) zu verstehen, in dessen Teilbereiche die Herausforderungen des demografischen Wandels gegliedert werden können. Nach Walter u. a. ([13], S. 8) lassen sich die Bedürfnisse der Arbeitswelt auf Basis der Handlungsfelder Arbeitsmarkt, Unternehmenspolitik, Arbeitsrecht, Bildungs- und Qualifizierungssystem, Sozialpartnerschaft und soziale Sicherung dimensionieren. Innerhalb der vier erstgenannten Handlungsfelder werden die Wechselwirkungen mit den demografischen Chancen „Änderung von Erwerbsbiografien" und „demografieorientierte Personalpolitik" [14] ersichtlich (vgl. Abb. 1). Diese Interdependenz gestaltet sich insofern, als die Erfordernisse einer zukunftsfähigen Arbeitswelt mit den demografischen Chancen in vielfacher Hinsicht korrespondieren, aber auch aus diesen hervorgehen. In diesem Spannungsfeld werden im Folgenden die vier Handlungsfelder Arbeitsmarkt, Unternehmenspolitik, Arbeitsrecht sowie Bildungs- und Qualifizierungssystem extrahiert und untersucht.

So ist im Kontext des Arbeitsmarktes die Sicherung des zukünftigen Fachkräftebedarfes als eine zentrale Herausforderung zu betrachten ([15], S. 17). Ehing/Moog [16] prognostizieren ab 2030 eine massive Absenkung der Zahl an erwerbstätigen Personen (vgl. [16], S. 16). Neben diesen personellen Gegebenheiten ist auch die qualifikatorische Ausgangslage der Erwerbstätigen zu berücksichtigen, weil die Arbeitsmarktperspektiven für „Geringqualifizierte strukturell ungünstiger verlaufen werden als für Hoch- und Gutqualifizierte" ([13], S. 38). Direkte Folge aus dieser Prognose ist die Chance, die Kompetenzentwicklung und Qualifizierung von Erwerbstätigen durch lebenslanges Lernen und kontinuierliche Kompetenzentwicklung zu forcieren ([17], S. 12 f.), aber auch Innovationsfähigkeit in Unternehmen durch eine Beteiligung aller Altersklassen und einer Generierung von Wissen in jeder Altersstufe zu stärken ([9], S. 16 ff.).

Als handlungsleitend im Bereich des unternehmenspolitischen Handlungsfeldes ([13], S. 19) kann eine „integrierte Strategie zur gleichzeitigen Stärkung von Flexibilität und Sicherheit auf dem Arbeitsmarkt" (Europäische Kommission 2013) angesehen werden. Im Kontext der Herausforderung der Unternehmen, ihre Wettbewerbsfähigkeit auch in Zukunft zu sichern, ergeben sich auf dieser Basis vielfach Konzepte zur Nutzung der demografischen Chancen. Hierbei sind Veränderungen in der Unternehmensorganisation und der Vernetzung der Unternehmen hin zu einer systematischen Organisationsgestaltung wie auch zu wandlungsfähigen Organisationsstrukturen ([5], S. 126) erforderlich, was die Entwicklung einer flexiblen Struktur im Sinne der demografischen Chancen unterstützt.

Im Kontext des Bildungs- und Qualifizierungssystems erfordert die Entwicklung zur Wissens- und Innovationsgesellschaft nach dem Grundsatz „Niemand darf verloren gehen" ([13], S. 74) eine Integration der Erwerbstätigen unabhängig von Alter, Migrationsstatus oder sozialer Herkunft in (Weiter-)Bildungsprozesse ([18], S. 4 f.). So stellt der Sachverständigenrat zur Begutachtung der gesamtwirtschaftlichen Entwicklung fest, dass „eine Steigerung der Produktivität der Erwerbstätigen mit positiven Effekten auf das Produktionspotenzial [. . .] durch vermehrte Bildungsanstrengungen möglich" ([11], S. 116) wäre. Hieraus resultieren zum einen die Entwicklung hin zu lebenslangen Lernprozessen, zum anderen ein kontinuierlicher Kompetenzerwerb in einem weiter entwickelten Bildungszyklus der Erwerbstätigen.

Als eine Hauptfunktion des Arbeitsrechts kann die Aufrechterhaltung einer Schutzfunktion der Erwerbstätigen angesehen werden, um im Rahmen „der prognostizierten demographischen, sozialen, wirtschaftlichen und auch technischen Entwicklungen" ([13], S. 95) den demografischen Chancen gerecht zu werden. Hierbei ist vor allem die Schaffung von juristischen Rahmenbedingungen für Arbeits- und Arbeitszeitmodelle in Unternehmen zu nennen, um so zum einen die rechtliche Dimension zur flexiblen Beschäftigung älterer Erwerbstätiger für sowohl Arbeitgeber als auch -nehmer zu gestalten ([19], S. 91) als auch zum anderen die Potenziale von atypischen Beschäftigungsmodellen auszuschöpfen. In diesem Zusammenhang sind im Besonderen die Untersuchung von Quantität und Qualität atypischer Beschäftigung Gegenstand der Forschung ([20], S. 10), mit der Möglichkeiten generiert werden, durch eine längere Beschäftigung älterer Erwerbstätiger Wissen in Unternehmen zu erhalten und so durch eine Zusammenarbeit der Generationen ein erhöhtes Innovationspotenzial zu schaffen.

Zu den dargestellten Handlungsfeldern und damit einhergehenden Chancen werden im Förderschwerpunkt *Innovationsfähigkeit im demografischen Wandel* praxisnahe Lösungen im Rahmen von insgesamt 27 transdisziplinären Verbundprojekten erforscht. In den Forschungsfeldern „Innovationspotenziale durch veränderte Erwerbsbiografien", „Messung von Innovationspotenzialen vor dem Hintergrund der demografischen Entwicklung" und „Regionale Aspekte des demografischen Wandels in der Arbeitswelt" [21] untersuchen diese Verbundprojekte in sechs thematischen Fokusgruppen (vgl. Abb. 1), wie die demografischen Chancen

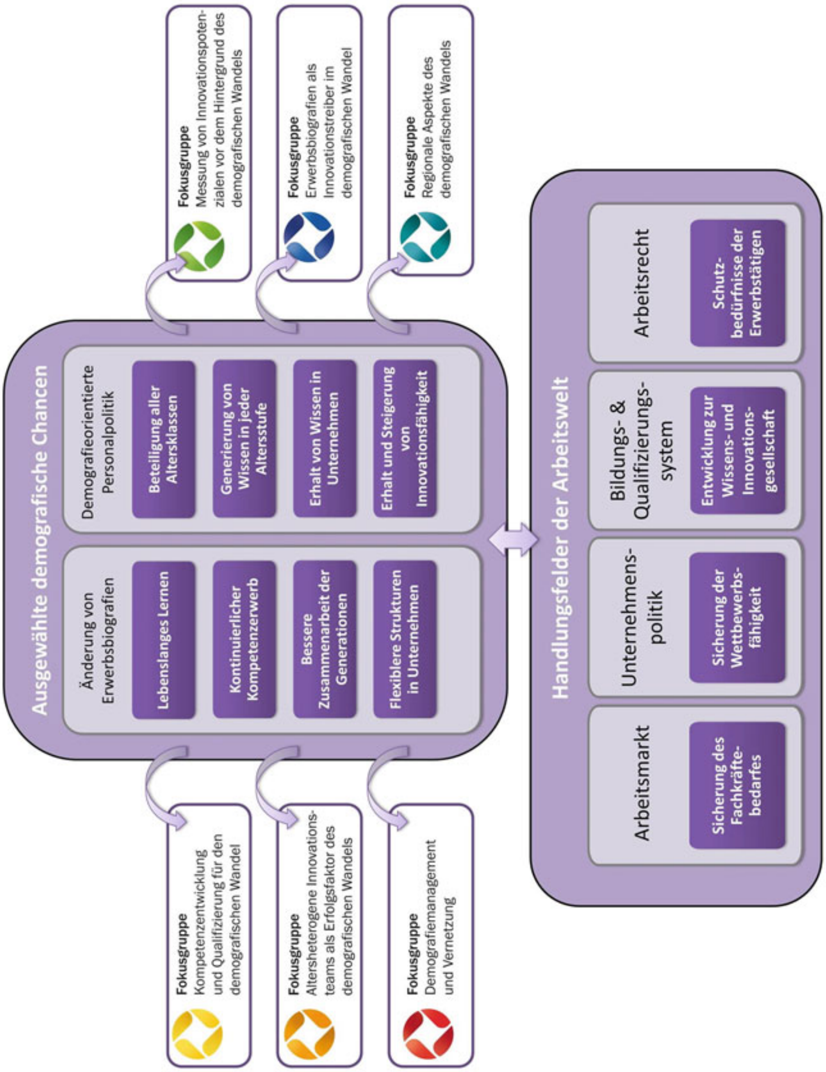


**Abb. 1** Interdependenzen der Handlungsfelder der Arbeitswelt (nach [13]), der demografischen Chancen (nach [14]) sowie den Fokusgruppen des Förderschwerpunktes Innovationsfähigkeit im demografischen Wandel. (Quelle: Eigene Darstellung)

genutzt werden können. Hierbei stehen die Entwicklung von „Konzepte[n] der Unternehmens- und Arbeitsorganisation sowie der Berücksichtigung von veränderten Erwerbsbiografien" ([22], S. 2) als Treiber dieser Chancen im Vordergrund der Forschung, um so die Innovationsfähigkeit von Unternehmen im Industrie- und Dienstleistungsstandort Deutschland zu erhalten und auszubauen.

## 3 Industrie 4.0 als Chance

Mit einem hohen Anteil der Erwerbstätigen,[2] die in Deutschland direkt oder indirekt an industriellen Produktionsprozessen beteiligt sind ([5], S. 8; [20], S. 49), ist die Bedeutsamkeit des Themas Industrie 4.0 als Zukunftstrend für den deutschen Industriestandort unverkennbar.

> Industrie 4.0 meint im Kern die technische Integration von CPS [Cyber-physischen Systemen] in die Produktion und Logistik sowie die Anwendung des Internets der Dinge und Dienste in industriellen Prozessen - einschließlich der sich hieraus ergebenden Konsequenzen für die Wertschöpfung, die Geschäftsmodelle sowie die nachgelagerten Dienstleistungen und die Arbeitsorganisation ([7], S. 18).

Besonderes Augenmerk wird in dieser Definition von Industrie 4.0 auf den Vernetzungsaspekt durch Informations- und Kommunikationstechnologien (IKT), die Verschmelzung von physischen, biologischen und technischen Systemen ([23], S. 3) zu CPS sowie die Auswirkungen auf weitere Unternehmensbereiche gelegt. Daraus ergibt sich, dass dieser Zukunftstrend in seinen unterschiedlichen Dimensionen eine Vielzahl von Fachdisziplinen beeinflusst und fordert, die an der Produktionsplanung, -abwicklung und -entwicklung beteiligt sind ([24], S. 43). Deutschland zeichnet sich nicht nur durch eine hohe Konkurrenzfähigkeit seiner Produktions- und Exportwirtschaft aus, sondern hat sich aufgrund der Fokussierung auf Erforschung, Entwicklung und Fertigung innovativer Produktionstechnologien als führender Fabrikausstatter etabliert ([7], S. 5). Um diese Spitzenposition auch in Zukunft verteidigen zu können, bedarf es eines weiteren Ausbaus des noch in der Entwicklung befindlichen Zukunftskonzeptes Industrie 4.0.

Innerhalb der Prozesse Produktion und Logistik sind CPS als (teil-)autonome Objekte zu verstehen, die als intelligent vernetzte Akteure in einem System agieren [25, 26]. Hierbei sind CPS nicht nur in der Lage, Informationen über Sensoren aufzunehmen, sondern innerhalb ihres Aufgabenspektrums durch die Anwendung von Aktoren zu handeln ([27], S. 738). Die Basis dieser Handlungsfähigkeit stellen geschlossene Regelkreise dar, die (Fertigungs-)Prozesse dynamisch abbilden ([28], S. 7). Im Gegensatz zur traditionellen Automatisierungstechnik kommunizieren CPS flexibel mit ihrer Umgebung und sind so in der Lage als „‚intelligente' Werkstücke [...] selbstständig den optimalen Weg durch die Fertigung [zu] finden" ([29], S. 20).

[2] Die Angaben in den Quellen schwanken zwischen 36 und 60 % der Beschäftigten, wobei in erster Linie definitorische Unterschiede Ursache der großen Spanne sein dürften.

Zur Modellierung der hierfür notwendigen Verhaltensregeln der CPS ist im Besonderen das Erfahrungswissen der Beschäftigten gefordert, über das vor allem ältere Mitarbeiter verfügen. Mit der Vielzahl ihrer Kenntnisse im Ablauf der Produktion auf einer interdisziplinäreren Basis können sie einen Beitrag zu einer sicheren und komplexitätsadäquaten Entwicklung leisten.

Darüber hinaus wird durch die sich entwickelnde Echtzeitübertragung von Produktionsdaten die dynamische Gestaltungsfähigkeit im Rahmen eines vormals starren Produktionsprozesses größer, was eine agilere Abwicklung sowohl von Engineering- als auch Geschäftsprozessen ermöglicht ([7, 30, S. 20]). Als direkte Folge dieser durch Echtzeitübertragung entstandenen neuen Datengrundlage lassen sich optimierte Entscheidungen hinsichtlich der Produktionsfolge und -abwicklung fällen. So kann auf eine zunehmende Individualisierung der Kundenwünsche flexibel reagiert und aufgrund der Rückkopplung von Informationen aus der Fertigung in den Produktentwicklungsprozess eine fertigungsoptimierte Gestaltung des jeweiligen Produktes gewährleistet werden. Damit leitet die vierte industrielle Revolution einen Paradigmenwechsel einerseits in der Mensch-Technik-, andererseits in der Mensch-Umgebungs-Interaktion ([7], S. 27) ein, der die Integration von Assistenzsystemen als unterstützende Elemente in Arbeitsabläufe ermöglicht [31]. Daraus wiederum erwachsen Chancen für die Schaffung von altersgerechten Beschäftigungsverhältnissen, eine Beteiligung aller Altersklassen am Produktionsprozess und demzufolge für die Sicherung von Fachkräften. Da im Zuge der Produktentwicklung zudem ein Großteil der eigentlichen Produktkosten festgelegt wird - nach Ehrlenspiel ([32], S. 608) immerhin zwischen 60 und 80 %-, ergibt sich aus der oben genannten Informationskopplung von Produktion und Entwicklung sowie aus der Beteiligung von älteren Beschäftigten am Produktionsprozess ein erheblicher Einflussfaktor auf die Ressourcenproduktivität und -effizienz, welche nach Kagermann u. a. ([7], S. 20) ebenfalls als Potenziale der vierten industriellen Revolution gelten. In diesem Sinne evoziert der Wandel zur Industrie 4.0 Möglichkeiten zu einer ganzheitlichen und innovativen Arbeitsgestaltung (vgl. Abb. 2).

Der prognostizierte Wandel in der Produktionstechnologie birgt aber nicht nur eine Vielzahl an technischen Potenzialen, sondern auch Chancen für kleine und mittelständische Unternehmen, die sich etwa als neue wertschöpfende Dienstleister im Bereich der IT-Dienstleistung etablieren und so innovative Strategien zum Umgang mit den oben genannten Fertigungsdaten entwickeln können ([7], S. 20). Zugleich erlaubt die Vernetzung der Produktion und die damit einhergehende Echtzeitkommunikation eine neue Mobilität in der Bearbeitung von Vorgängen ([33], S. 15) sowie Flexibilität in der Struktur von Unternehmen und in den Arbeitsabläufen, was sich wiederum förderlich auf die Vereinbarkeit von Familie und Beruf auswirkt [31].

Mit dem Wandel zur Industrie 4.0 und der zunehmenden Flexibilisierung von Produktionsvorgängen verändert sich auch die Rolle des Menschen im Arbeits- und Produktionsprozess: interdisziplinäre Zusammenarbeit wird immer wichtiger. Aus diesem Grund werden in Einrichtungen und Netzwerken, die in diesem Kontext forschen und arbeiten, auch neue Management- und Wissensvermittlungsansätze

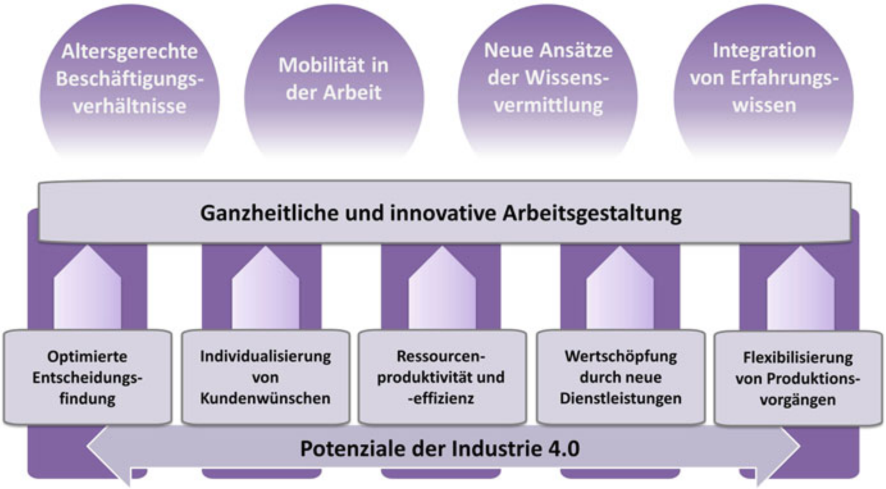


**Abb. 2** Potenziale der Industrie 4.0 und damit verbundene Chancen. (Quelle: Eigene Darstellung in Anlehnung an [7])

entwickelt, um mit bedarfsgerechten Maßnahmen[3]. den Transfer von Wissen und Erkenntnissen zu etablieren ([34], S. 378), der Zunahme an interdisziplinärer Entwicklungsarbeit gerecht zu werden und die Innovationsfähigkeit zu stärken. Diese Wissensvermittlungsmaßnahmen werden nach der eigentlichen Berufsausbildung implementiert und forcieren so zum einen Aspekte des lebenslangen Lernens. Zum anderen tragen insbesondere interdisziplinär gestaltete Maßnahmen zu einem kontinuierlichen Kompetenzerwerb bei, auch über die eigentliche Fachqualifikation hinaus.

## 4 Zusammenfassung und Ausblick

Auf die Arbeitswelt von morgen wartet eine Vielzahl von Herausforderungen und Chancen. Die demografische Dimension dieser Chancen materialisiert sich unter anderem in Veränderungen des Arbeitsmarktes, der Unternehmenspolitik oder der Bildungs- und Qualifizierungssysteme. In Hinblick auf diese und weitere Dimensionen wird im Förderschwerpunkt *Innovationsfähigkeit im demografischen Wandel* zu Konzepten der Unternehmens- und Arbeitsorganisation geforscht. Im Unterschied zu diesen Forschungsbestrebungen, die sich mit menschlich-personalen und organisationalen Aspekten befassen, wurden im vorliegenden Beitrag vor allem die technischen Entwicklungen berücksichtigt und auf ihre Bedeutung für die Gestaltung

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[3] Aktuelle Maßnahmen in diesem Kontext können unter http://www.production-research.de unter Scientific Cooperation Engineering eingesehen werden (Zugriff vom 19.06.2013).

des demografischen Wandels hin befragt. Als ein mögliches Zukunftskonzept wurde die Industrie 4.0 herangezogen. Dies nicht nur deshalb, weil mit ihr die Möglichkeit gegeben ist, zukünftigen Anforderungen des Technologiemarktes flexibel zu begegnen, sondern auch Bedarfe auf organisationaler und menschlicher Ebene auf- und damit demografischen Entwicklungen vorzugreifen. Denn das kompetitive Werben um Arbeitskräfte - und zwar unabhängig von deren Alter, Geschlecht, sozialer und nationaler Herkunft - muss so flexibel und arbeitsorientiert gestaltet sein wie die Wünsche auf Seiten der Mitarbeiter und Mitarbeiterinnen vielfältig sind.

Entsprechend handelt es sich bei der Industrie 4.0 nicht einfach um die Novellierung tradierter tayloristischer Formen der Arbeitsorganisation und Organisationsgestaltung. Sie ist vielmehr ein ßozio-technisches Fabrik- und Arbeitssystem ([35], S. 53) und als solches komplexer, virtueller und disziplinär vielfältiger als irgendeiner ihrer Vorläufer. Insofern ist sie bestens darauf vorbereitet, den heterogenen Voraussetzungen und diversen Wissens-, Erfahrungs- und Kompetenzniveaus der erwerbsfähigen Bevölkerung in einer demografisch veränderten Gesellschaft nicht nur reaktiv zu begegnen, sondern diese proaktiv und hinsichtlich innovatorischer Potenziale zu nutzen.

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# Innovationsförderliches Knowledge Engineering in inter- und transdisziplinären Forschungsverbünden

**Claudia Jooß, Florian Welter, Ingo Leisten, Anja Richert und Sabina Jeschke**

**Zusammenfassung** Sowohl der globale Wettbewerb als auch der daraus resultierende Druck, innovationsfähig zu bleiben (vgl. Mainzer, Interdisziplinären. Theorie, Praxis, Probleme., 2010, VII), sind von besonderer Bedeutung für das Konzept moderner Forschung und Entwicklung, die verstärkt in großen Forschungsverbünden stattfindet. Um der vorherrschenden Komplexität solcher Verbünde und den gleichzeitig hohen Erwartungen, etwa an die Innovationskraft, gerecht zu werden, sind Eigenschaften wie „synergetische" Kooperationsstrukturen und die Ausbildung „emergenten" Verhaltens notwendig. Hierzu benötigen Forschungsverbünde angemessene Ansätze, die die Vernetzung verschiedener Disziplinen, Kompetenzen, Wissen, (wissenschaftlicher) Erfahrungen und Kulturen so unterstützen, dass ein innovationsförderliches Milieu entsteht. In diesem Artikel wird ein innovationsförderlicher Knowledge Engineering Ansatz vorgestellt, der prozessbegleitend in inter-und transdisziplinären Forschungsverbünden implementiert und weiterentwickelt wird.

**Schlüsselwörter** Interdisziplinarität · Transdisziplinarität · Wissensintensive Prozesse

## 1 Einleitung

Wissen ist neben den klassischen Produktionsfaktoren Land, Arbeit und Kapital zum wichtigsten Produktionsfaktor des gegenwärtigen Jahrhunderts in hoch entwickelten Volkswirtschaften geworden[1]. Der innovationspolitische Trend der vergangenen Jahre, verstärkt inter- und transdisziplinäre Forschungsverbünde zu fördern, weist

[1] „Wissen ist damit die wichtigste Ressource des Individuums wie auch der gesamten Gesellschaft. Grundbesitz, Arbeit und Kapital – [. . . ] die traditionellen Produktionsfaktoren – sind zwar nicht verschwunden, aber zweitrangig geworden" Drucker [11, S. 81].

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darauf hin, dass monodisziplinäres Wissen als Ressource zur Problemlösung und Weiterentwicklung moderner Volkswirtschaften nicht mehr ausreicht, sondern die Wissensbestände mehrerer Disziplinen von Nöten sind, um die vorherrschenden komplexen Problemstellungen zu bewältigen[2]. Dadurch ist die Bedeutung und gleichsam das Management inter- und transdisziplinärer Forschungsverbünde in den vergangenen Jahren immer mehr in den Fokus des Interesses gerückt (z. B. von Forschungsnehmern wie Hochschulen oder außeruniversitären Einrichtungen sowie Forschungsförderern in Form von Ministerien, Forschungsgemeinschaften,etc.) (vgl. u. a. [9, 12, 16, 21, 26, 28, 39, 41]). Insbesondere die Installierung großer interdisziplinärer Forschungsverbünde, wie u. a. durch die deutsche Exzellenzinitiative geschehen, erfordert die Hinwendung zu folgenden zentralen Fragestellungen solcher Konstrukte:

- Welche Herausforderungen stellen sich durch die disziplinenübergreifende Zusammenarbeit für die Unterstützung der Innovationsfähigkeit komplexer Forschungsverbünde? (vgl. Kap. 2)
- Wie kann diesen Herausforderungen begegnet werden? (vgl. Kap. 3)
- Welche Konsequenzen hat der Umgang mit den Herausforderungen für die Innovations- und Förderpolitik? (vgl. Kap. 4)

Forschen in disziplinenübergreifenden Forschungsverbünden wird in der Fachliteratur als sogenannter zweiter Modus bezeichnet (vgl. [9, 32]). Anstelle einer rein akademisch und streng disziplinär geprägten Wissenserzeugung in Forschungsprojekten tritt eine veränderte Art des Forschens, die sich gesellschaftlichen Problemstellungen widmet. Diese ist durch die enge Kooperation hinsichtlich zahlreicher Methoden und Disziplinen aus den einzelnen Wissenschaften sowie durch die enge Zusammenarbeit von (interdisziplinär zusammengesetzter) Forschung und Praxis geprägt (vgl. [14]). Insbesondere werden durch die Initiierung interdisziplinärer Forschungsverbünde sogenannte „effects of synergy“[3] erwartet.

Daher kommt der Wissenserzeugung in interdisziplinären Forschungsverbünden eine erfolgskritische Bedeutung zu: Die Entwicklung, die Nutzung und der Transfer von Wissen entscheiden über das Potenzial, die geforderten Innovationen hervorzubringen und damit über den Erfolg des Forschungsverbunds (vgl. [26]).

[2] Within the framework of the German Research Foundation (DFG) and the Science Council (WR) the excellence initiative of the German federal and state governments, about 2,7 billion € have been made available to strengthen top-level research at German universities. (http://www.dfg.de/service/presse/pressemitteilungen/2010/pressemitteilung_nr_12/index.html). On the European level 3 % of the gross national product, following the Lisbon aims, shall be invested annually in research and development till 2010 – according to the OECD the joined countries currently invest about 650 million € annually (www.oecd.org/dataoecd/18/32/41551978.pdf).

[3] Synergie ist die Interaktion von verschiedenen Komponenten in einem System. Durch die Interaktion zeigt das System Fähigkeiten und ein Verhalten, welches nicht durch die Summe der Fähigkeiten seiner Komponenten erreicht werden kann. Wenn diese Interaktion zudem auf ein Ziel ausgerichtet ist, ist es möglich, dass Emergenz auftritt. Dies bedeutet, dass ein bestimmtes Verhalten nicht auf Basis des Verhaltens der Komponenten vorhersagbar ist. In Organisationen kann dies durch geteilte Werte und Visionen erreicht werden (vgl. [36]).

Dabei entsteht die Frage, wie solche „wissensintensiven Prozesse" ([42, S. 208]), die mitunter schwer zu explizieren bzw. zu standardisieren sind, gezielt unterstützt und gestaltet – in anderen Worten ‚engineert'[4] werden können (vgl. [42, S. 208]).

Die gleichzeitige Gestaltung und Integration wissensintensiver Prozesse über die Dimensionen

- Mensch (z. B. Kompetenzausbau),
- Organisation (z. B. effektive Teamstrukturen)
- und Technik (z. B. stabile Wissensmanagementsysteme)

erscheint dabei als ein entscheidender Ansatz, mit dem beispielsweise Anforderungen von Nutzern (Dimension: Mensch) zur Gestaltung organisationaler Strukturen (Dimension: Organisation) und technischer Lösungen (Dimension: Technik) erfasst und zielgruppenspezifisch umgesetzt werden können. Dies zeigen auch relevante Veröffentlichungen zur Gestaltung inter- und transdisziplinärer Forschungsverbünde. Beispielsweise plädieren Bergmann et al.: „*Erst Integration auf einer kognitiven, aber auch auf einer sozialen, einer kommunikativen, einer organisatorischen und möglicherweise auch auf einer technischen Ebene führt dazu, dass die transdisziplinäre Forschung gute Ergebnisse zu erzielen vermag*" ([9, S. 10]). Um die Herausforderungen, die sich durch disziplinenübergreifende Zusammenarbeit für die Unterstützung der Innovationsfähigkeit solcher Forschungsverbünde ergeben herauszustellen, werden im folgenden Abschnitt zusammenfassend die verschiedenen „Integrationsmodi" von Forschungsprozessen aufgeführt.

## 2 Integrationsmodi unterschiedlicher Disziplinen im Forschungsprozess

Wenn sich mehrere wissenschaftliche Disziplinen in einen gemeinsamen Forschungsprozess begeben, ist dieser in vielen Fällen nicht einem Integrationsmodus (multi-, inter-, transdisziplinär etc.) zuzuordnen. Vielmehr ändert sich der Prozess, je nach Gegenstandsbereich, Methoden, Art des Erkenntnisinteresses, der Kooperationsstruktur, usw. in einen anderen Modus. Um die Herausforderungen für das innovationsförderliche Engineering solcher Wissenserzeugungsprozesse besser zu verstehen, werden ausgewählte Modi der Zusammenarbeit thematisiert[5].

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[4] Die Begriffe „Engineering" und „Knowledge Engineering" sind dabei im Fachdiskurs zunächst eher technisch geprägt. Betrachtet man unterschiedliche Definitionen von Engineering haben alle das Ziel der Verbesserung von technischen Entwicklungs- und Arbeitsprozessen gemeinsam (vgl. [22]). Im vorliegenden Verständnis von Knowledge Engineering werden Strukturen und Prozesse modelliert und implementiert, die Kommunikation und Kooperation in den untersuchten Forschungsverbünden unterstützen. Die anwendungsorientierte Forschung mündet in Erkenntnissen, Dienstleistungen und Produkten, wobei die Kunden und Nutzer iterativ und kooperativ in die Lösungsfindung einbezogen werden.

[5] In der aktuellen Wissenschaftsdiskussion gibt es nur wenige Begriffe, bei denen eine so hohe Diskrepanz zwischen der Häufigkeit der Nutzung und der theoretischen Reflexion zu finden ist, wie

### 2.1 Multidisziplinaritität in Wissenschaft/Forschung

Im Fall von Multidisziplinarität in Wissenschaft und Forschung arbeiten verschiedene Disziplinen unabhängig voneinander an einem gemeinsamen Problem. Dabei erfolgt keine Integration der Methoden. Multidisziplinarität wird durch eine unabhängige Anwendung von Methoden mit disziplinären Resultaten gekennzeichnet, da sie „eine Vielfalt an Disziplinen [beschreibt], die gleichzeitig angeboten werden, aber ohne dabei mögliche Beziehungen zwischen eben diesen deutlich zu machen“ ([17, S. 106]). Trotz des fachübergreifenden Gegenstandes lässt sich die Kooperationsstruktur als ein „disziplinäres Nebeneinander“ ([21, S. 2]) beschreiben.

### 2.2 Interdisziplinarität in Wissenschaft/Forschung

Interdisziplinarität in Wissenschaft und Forschung bedeutet, dass verschiedene wissenschaftliche Disziplinen ein gemeinsames Problem bearbeiten. Im Gegensatz zur Multidisziplinarität beschäftigt sich Interdisziplinarität mit der Integration und Kombination von wissenschaftlichen Methoden, Paradigmen, Problemen, Fragen, etc. Die Ergebnisse interdisziplinärer Kooperation intendieren, die Summe disziplinärer Resultate zu übertreffen (vgl. [10]). Interdisziplinarität beschäftigt sich außerdem mit dem Verstehen und Erforschen neuer Forschungsgebiete (vgl. [21, S. 4]). Die Herausforderungen des Engineerings interdisziplinärer Wissensprozesse sind vielfältig. Eine grundlegende Schwierigkeit besteht beispielsweise darin, das Verständnis über den gemeinsamen Forschungsgegenstand zu sichern. Die unterschiedliche Terminologie der Wissenschaftsdisziplinen führt häufig zu Missverständnissen in der Wissensproduktion, deren Klärung zeit- und ressourcenintensiv ist. Daher werden Ansätze benötigt, die dabei unterstützen, terminologischen Schwierigkeiten zu überwinden, um unterschiedliche Begriffsverständnisse einzelner Disziplinen zur synergetischen Grundlage von Innovationsprozessen avancieren zu lassen (vgl. [40]).

### 2.3 Transdisziplinarität in Wissenschaft/Forschung

Der Unterschied zu Interdisziplinarität ist das Ineinandergreifen verschiedener Prozesse: Forschung und Praxis forschen gemeinsam und gleichberechtigt. Deshalb ist dieses Verständnis durch die Integration und Kombination von verschiedenen wissenschaftlichen Methoden und praktischem Wissen/Ausübungen (vgl. [6, 30]) gekennzeichnet. Konstrukte wie Demografie und Globalisierung, sind ein Beispiel

es beim Begriff der Interdisziplinarität der Fall ist (vgl. [21, S. 1]). Da es nicht Ziel dieses Artikels ist, die unterschiedlichen Begriffe (Disziplinarität, Multi-/Pluri-/Cross-/Inter-/Transdisziplinarität) aufzuarbeiten, werden im Folgenden nur die im Kontext relevanten Begriffe zusammenfassend eingeführt.

dafür: drängende gesellschaftliche Probleme werden von der Wissenschaft aufgegriffen, in wissenschaftliche Fragestellungen übersetzt und domänenübergreifend (verschiedene wissenschaftliche Disziplinen und außerwissenschaftliche Akteure) bearbeitet (vgl. [6, 16, 26]).

Zusammenfassend kann demnach konstatiert werden, dass die zentralen Herausforderungen für ein innovationsförderliches Knowledge Engineering von inter- und transdisziplinären Forschungsverbünden in folgenden zentralen Aspekten liegt:

- Die Verbindung verschiedener Kompetenzen, Wissen, heterogener Zielsetzungen von Institutionen und Akteuren (verschiedene Forscher und Ausübende/Praktizierende)
- und die Integration und Kombination verschiedener wissenschaftlicher Methoden (wissenschaftssystematische Triangulation) und praktischem Wissen/Ausübungen.

Die mehrdisziplinäre Zusammenarbeit zur Bearbeitung komplexer und hybrider Probleme kann jedoch auch zu Spannungen und Konflikten bei der Kooperationsgestaltung führen (vgl. [28, S. 7]). Hieraus erklärt sich die hohe Nachfrage nach strukturellen und verfahrenstechnischen Rahmenbedingungen. Daher widmet sich der nachfolgende Abschnitt der Frage, wie Kooperation in inter- und transdisziplinären Forschungsverbünden effektiv und effizient gestaltet werden kann.

## 3 Knowledge Engineering in inter- und transdisziplinären Forschungsverbünden

Knowledge Engineering hat sich in den letzten Jahren in verschiedenen Projekten und Forschungsverbünden als innovativer Ansatz zur Unterstützung und Entwicklung wissensintensiver Prozesse, z. B. mit Blick auf die Kommunikation und die Kooperation zwischen Akteuren aus unterschiedlichen Disziplinen, etabliert (vgl. Kap. 3, vgl. [18, 20]).

In Anlehnung an VDI-Richtlinie 2221 untergliedert sich Knowledge Engineering – im Sinne eines iterativen Prozesses – in verschiedene Teilschritte (vgl. Abb. 1). Das Durchlaufen der Teilschritte, beginnend mit der Klärung und Präzisierung der Aufgabenstellung bis hin zur Ausarbeitung spezifizierter Ausführungs- und Nutzerangaben, dient dabei einer kontinuierlichen Entwicklung, Reflektion und Anpassung zielgruppenadaptiver Dienstleistungs- und Forschungsfelder von inter- und transdisziplinären Forschungsverbünden.

Knowledge Engineering in inter- und transdisziplinären Forschungsverbünden fokussiert auf eine zielgruppenadaptive Entwicklung von Dienstleistungsfeldern, im Sinne von unterstützenden Maßnahmen zur Organisation und zum Management von Forschungsverbünden (vgl. [8]), und Forschungsfeldern auf den Dimensionen Mensch, Organisation und Technik. Hier ist hervorzuheben, dass Dienstleistungs- und Forschungsfelder in einem kontinuierlichen Austauschverhältnis zueinander in


**Abb. 1** Knowledge Engineering (in Anlehnung an VDI-Richtlinie 2221)

Beziehung stehen. Beispielsweise ermöglicht die parallele Umsetzung von Maßnahmen und deren Erforschung einen schnelleren felddatenbasierten Erkenntnisgewinn als die Durchführung von Dienstleistungs- und Forschungsfeldern in sequenzieller Form. Durch die kontinuierliche Rückführung von Erkenntnissen und das wiederholte, iterative Durchlaufen der Teilschritte wird eine fortlaufende Optimierung der Dienstleistungs- und Forschungsfelder bereits während des Projektverlaufs ermöglicht (vgl. Abb. 1).

Die Umsetzung klassischer Dienstleistungen bzw. „Netzwerkservices" ([8]), die in vergleichbaren Verbundformen – unter Annahme des Durchlaufens relativ statischer Netzwerkentwicklungsphasen[6] und dazugehöriger Herausforderungen – implementiert werden, erscheinen vor dem oben beschriebenen Hintergrund als nicht mehr hinreichend (vgl. [23]). Im Folgenden werden aus diesem Grund zentrale Erkenntnisse und Beispiele aus der Anwendung von Knowledge Engineering zur iterativen Entwicklung von zielgruppenadaptiven Dienstleistungs- und Forschungsfeldern in inter- und transdisziplinären Forschungsverbünden aufgezeigt.

[6] Das Durchlaufen klassischer Netzwerkentwicklungsphasen wird in der Literatur auch verbreitet für Forschungsverbünde angenommen (vgl. [2, 12, 31]). Klassische Netzwerkentwicklungsphasen umfassen in Anlehnung an Ahrens [2] die Initiierungsphase, die Stabilisierungsphase und Verstetigungsphase.

### 3.1 Interdisziplinärer Exzellenzcluster Integrative Produktionstechnik für Hochlohnländer (2006 bis 2017)

Die Phasen der klassischen Entwicklung von (Forschungs-)Netzwerken betreffend, zeigen beispielsweise Ergebnisse aus der ersten Förderphase des Exzellenzclusters Integrative Produktionstechnik für Hochlohnländer an der RWTH Aachen, dass typische Eigenschaften der Netzwerkentwicklung und dazugehörige Dienstleistungen nicht mehr nur einer einzelnen Netzwerkentwicklungsphase zugewiesen werden können[7]. Ahrens' Modell [2] zufolge bezieht sich das charakteristische „Setzen der Ziele eines Netzwerks" [2] auf die Initiierungsphase. Unsere Forschung zeigt jedoch: obwohl das „Setzen der Ziele eines Netzwerks" [2] typischerweise in der Initiierungsphase beobachtet werden kann, ist eine wiederholte Kommunikation, ggf. auch Anpassung, der Zielsetzung für alle Mitarbeiter des Exzellenzclusters von großer Bedeutung. Begründet wird diese Annahme z. B. mit der für Exzellenzcluster typischen Mitarbeiterfluktuation, die u. a. auf eine hohe Anzahl an zeitlich befristet eingestellten Doktoranden zurückzuführen ist, und die Verzögerungen der Netzwerkentwicklung in einigen Aspekten, wie beispielsweise des gemeinsamen Verständnisses über den F&E Prozess, zur Folge hat. Aufgrund dieser Begebenheit kann eine tendenziell statische Zuordnung von Dienstleistungen zu den klassischen Phasen der Netzwerkentwicklung (Initiierung, Stabilisierung, Verstetigung) nicht länger aufrechterhalten werden. Eine kontinuierliche und iterative Integration, Evaluation und Weiterentwicklung von Dienstleistungs- und Forschungsaktivitäten sind aus diesem Grund von besonderer Bedeutung.

Durch die Implementierung des Knowledge Engineering Ansatzes wurden für die zweite Förderperiode des betrachteten Exzellenzclusters (2012 bis 2017) vier Dienstleistungs- und Forschungsfelder im Rahmen der sogenannten Cross Sectional Processes (CSP) 1 identifiziert (vgl. [24]) (vgl. Abb. 2):

- Performance Measurement
  - Umfasst u. a. direkt messbare (harte) Kennzahlen und indirekt messbare (weiche) Kennzahlen von Kooperationsprozessen
- Interdisciplinary Innovation Management
  - Zielt z. B. auf die Analyse, Visualisierung und Förderung interdisziplinärer Publikationsprozesse
- Knowledge & Cooperation Engineering
  - Fokussiert u. a. Instrumente und Maßnahmen zur Erfassung und Förderung interdisziplinärer Wissensbestände

[7] Das IMA/ZLW & IfU der RWTH Aachen ist seit Gründung des Exzellenzclusters Integrative Produktionstechnik für Hochlohnländer im Jahr 2006 u. a. mit der Ausführung der sogenannten Cross Sectional Processes (CSP) betraut, die insbesondere auf eine Quervernetzung und Weiterentwicklung der wissenschaftlichen Prozesse des Exzellenzclusters abzielen. Der Exzellenzcluster wird seit 2012 für weitere fünf Jahre seitens der DFG gefördert.


**Abb. 2** Zentrale Dienstleistungs- und Forschungsfelder der Cross Sectional Processes (CSP) 1 im Exzellenzcluster Integrative Produktionstechnik für Hochlohnländer

- Diversity Management
  - Befasst sich mit Instrumenten und Maßnahmen auf den Diversity-Dimensionen Geschlecht, Alter und (Fach-)Kultur der Clusterakteure

## *3.2 Interdisziplinärer Exzellenzcluster Tailor-Made Fuels from Biomass (TMFB) (2007 bis 2017)*

Auch im Exzellenzcluster Tailor-Made Fuels from Biomass (TMFB) an der RWTH Aachen tragen Ursachen, wie z. B. Mitarbeiterfluktuation, zur Verschleppung der Charakteristika von einer Netzwerkentwicklungsphase in fortfolgende Phasen der Netzwerkentwicklung bei. Eine Maßnahme für ein erfolgreiches Engineering der Wissensproduktionsprozesse unter diesen Bedingungen war es, in diesem Cluster den Forschungsprozess und seine verschiedenen Routen zu visualisieren und alle beteiligten Akteure mitsamt ihren Routen im Forschungsprozessbild zu verorten.

Seit dem Jahr 2007 wird auch in TMFB ein Knowledge Engineering Ansatz implementiert, der „Collaboration-Enhancing Services" [13] mit „Collaboration-Enhancing Research" [13] unter dem Dach der sogenannten Supplementary Cluster Activities (SCA) verbindet. Seit der Verlängerung der Projektlaufzeit des Exzellenzclusters um weitere fünf Jahre (2012 bis 2017) befassen sich zentrale Aspekte der SCA zur Förderung der interdisziplinären Zusammenarbeit mit den Themen:

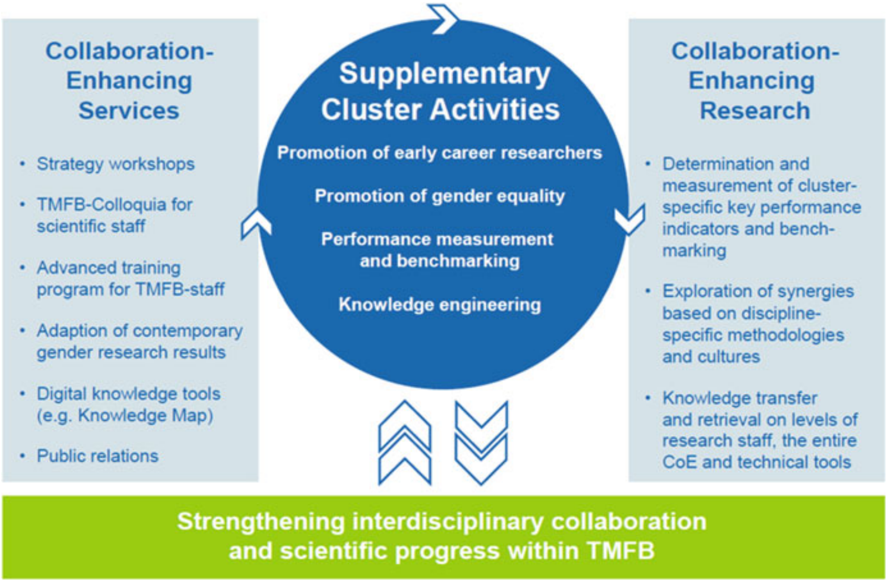


**Abb. 3** Collaboration-Enhancing Services und Collaboration-Enhancing Research im Exzellenzcluster Tailor-Made Fuels from Biomass [13]

- Promotion of Early Career Researchers
  - Befasst sich z. B. mit zielgruppenspezifischen Weiterbildungsmaßnahmen für Doktoranden
- Promotion of Gender Equality
  - Umfasst Maßnahmen zur Förderung von Chancengleichheit zwischen Wissenschaftlerinnen und Wissenschaftlern
- Knowledge Engineering
  - Zielt u. a. auf die Implementierung von Wissenslandkarten zur Visualisierung von Netzwerkakteuren und ihren Kompetenzfeldern
- Performance Measurement and Benchmarking
  - Entwickelt u. a. Ansätze zur Regelung wissenschaftlicher Exzellenzcluster auf den Dimensionen: Prozesse und Outputs

Dem bereits beschriebenen Knowledge Engineering Ansatz entsprechend wird die Performance des Exzellenzclusters (z. B. hinsichtlich der Dimensionen: Prozesse und Outputs) einerseits im Sinne einer Dienstleistungsaktivität gemessen, bewertet und zur Initiierung eines kontinuierlichen Verbesserungsprozesses an alle Clusterakteure zurückgeführt. Andererseits bildet Performance Measurement einen eigenen Forschungsgegenstand der SCA, der, auf Grundlage von Erkenntnissen aus bereits geleisteten Dienstleistungsaktivitäten, dynamisch weiterentwickelt wird (vgl. Abb. 3).

### *3.3 Transdisziplinärer Förderschwerpunkt „Innovationsfähigkeit im demografischen Wandel" des Bundesministeriums für Bildung und Forschung (BMBF) (2012 bis 2015)*

Die 26 bundesweiten Projekte des BMBF Förderschwerpunkts „Innovationsfähigkeit im demografischen Wandel" untersuchen zwischen 2011 und 2015, wie der demografische Wandel dazu genutzt werden kann, die Innovationsfähigkeit durch Konzepte der Unternehmens-, Personal- und Arbeitsorganisation nachhaltig zu steigern.

Sechs thematisch zusammengestellte Fokusgruppen, die durch das Metaprojekt „DemoScreen – Kommunikation, Kooperation und Innovationsfähigkeit im demografischen Wandel" begleitet werden, erarbeiten Ideen für die Entwicklung innovativer und innovationsförderlicher Lösungen für Politik, Wirtschaft, Wissenschaft und Gesellschaft zur Identifikation und Nutzung der Potenziale des demografischen Wandels[8].

Seit dem Jahr 2012 findet Knowledge Engineering innerhalb der Struktur des Metaprojekts DemoScreen seine Anwendung. DemoScreen entwickelt innovative Ansätze zur Steuerung von komplexen und vielschichtigen Forschungsverbünden, erzielt Erkenntnisse bei der Nutzung innovativer Methoden zur Verbreitung von Projektergebnissen und unterstützt die kontinuierliche Weiterentwicklung des Förderschwerpunkts. Dienstleistungs- und Forschungsfelder (hier: Handlungsfelder) des Metaprojekts unterstützen die förderschwerpunktinterne Vernetzung, die zielgruppengerechte externe Adressierung, die Nutzung von Synergien zwischen den Projekten sowie eine praxisorientierte Gestaltung des Transfers wissenschaftlicher Erkenntnisse (vgl. Abb. 4).

Die vier Handlungsfelder Vernetzung und Allianzbildung, Methodenintegration und Zielgruppenadaption, Dissemination und Befähigung sowie Operationalisierung und Bewertung, umfassen folgende Schwerpunkte:

- Vernetzung und Allianzbildung:
  - Zielt auf die reale und virtuelle Zusammenführung der Akteure (z. B. Unterstützung der Fokusgruppenvernetzung durch Arbeitstreffen, Entwicklung einer virtuellen Plattform)
- Methodenintegration und Zielgruppenadaption:
  - Umfasst die Unterstützung der Verbundprojekte bei der Generierung transdisziplinärer Lösungen und der Wahl der geeigneten Transferstrategie (z. B. Workshopreihe zur Erfassung der unterschiedlichen Forschungsansätze der

[8] „Ein Metaprojekt ist ein Förderinstrument innerhalb der Programmförderung des Bundesministeriums für Bildung und Forschung (BMBF). Jedes Metaprojekt ist einem Förderschwerpunkt des BMBF zugeordnet und unterstützt und übernimmt die Kommunikation und Kooperation der Akteure innerhalb dieses Schwerpunktes. Außerdem übernimmt das Metaprojekt die Rolle eines ‚Mediators', der Aktivitäten anderer Organisationen im nationalen und internationalen Kontext verfolgt und für diesen Förderschwerpunkt Kooperationsmöglichkeiten einleitet und unterstützend begleitet" (Wikipedia in Anlehnung an [3]).

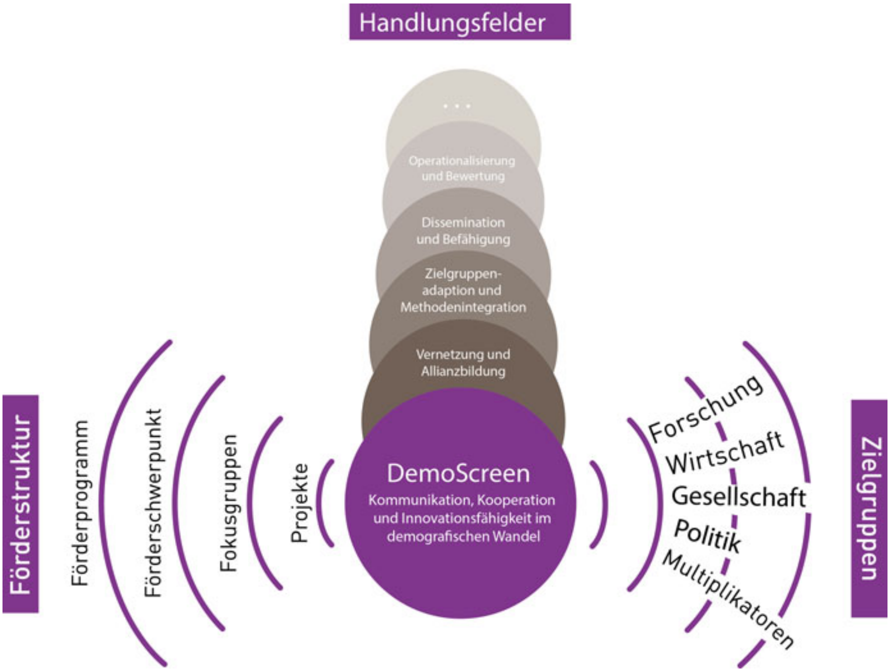


**Abb. 4** Metaprojekt DemoScreen: Handlungs-/Forschungsfelder, Förderstruktur und Zielgruppen

  einzelnen Projekte, Storyboards für Microtrainings zur Entwicklung modularer Kurzlerneinheiten für den Ergebnistransfer)
- Dissemination und Befähigung:
  – Beinhaltet die Unterstützung der Verbundprojekte bei der Verbreitung ihrer Ergebnisse (z. B. Förderschwerpunkt-Tagungen, Angebote für Multiplikatoren und eine umfassende Transferberatung).
- Operationalisierung und Bewertung:
  – Intendiert, zentrale Fachbegriffe bzw. Konstrukte wie Innovationsfähigkeit, demografischer Wandel greifbar zu machen und deren Entwicklung zu untersuchen (z. B. Bündelung und Systematisierung der Förderschwerpunkt-Publikationen, Entwicklung einer Screening-Methode für Begriffe sowie Kommunikations- und Kooperationsprozesse, Visualisierung disziplinspezifischer Verwendung von Fachbegriffen)

## 4 Ausblick

Der vorgestellte innovationsförderliche Knowledge Engineering Ansatz umfasst ein prozessorientiertes Vorgehen, das die wechselseitige Entwicklung von Dienstleistungs- und Forschungsfeldern, vor dem Hintergrund der Dimensionen:

Mensch, Organisation und Technik adressiert. Hierdurch kann dem Ansatz ein generischer Charakter zugeschrieben werden. Mit Hilfe der iterativen Entwicklung von Dienstleistungs- und Forschungsfeldern in Teilschritten, ist eine maßgeschneiderte Adaption auf unterschiedliche Rahmenbedingungen und Anforderungen inter- und transdisziplinärer Projekte, Verbünde, Cluster und vergleichbarer Vorhaben möglich (vgl. Abb. 1). Zukünftige Herausforderungen für Dienstleistungs- und Forschungsfelder in inter- und transdisziplinären Forschungsverbünden, denen mit Hilfe von Knowledge Engineering begegnet werden kann, betreffen beispielhaft nachfolgende Bereiche und werfen die folgenden Forschungsfragen auf[9]:

- Wissenschaftsmanagement von inter- und transdisziplinären Forschungsverbünden
  - Welche virtuellen und physischen Werkzeuge eignen sich zum Wissenschaftsmanagement inter- und transdisziplinärer Forschungsverbünde?
- Konzepte zum Performance Measurement, Benchmarking und zur Wissensbilanzierung inter- und transdisziplinärer Forschungsverbünde
  - Mit Hilfe welcher Konzepte lassen sich Prozesse und Outputs inter- und transdisziplinärer Forschungsverbünde operationalisieren, vergleichen und bewerten?
- Begriffsbildung in inter- und transdisziplinären Forschungsverbünden
  - Wie können Verständigungs- und Aushandlungsprozesse bezüglich zentraler Begriffe in inter- und transdisziplinären Forschungsverbünden unterstützt werden?

Nicht zuletzt ist auch das prozessorientierte Vorgehen des innovationsförderlichen Knowledge Engineering Ansatzes selbst als Gegenstand einer kontinuierlichen Reflektion durch Anwender zu verstehen, so dass die Adaption und Integration neuer Erkenntnisse in den bestehenden Ansatz erfolgen kann und damit dem Knowledge Engineering Ansatz ein im Kern kybernetischer Charakter zugeschrieben werden kann.

**Danksagung** Die vorgestellte Forschung wurde durch die DFG als Teil des Exzellenzclusters „*Integrative Produktionstechnik für Hochlohnländer*“ und des Exzellenzclusters „*Maßgeschneiderte Kraftstoffe aus Biomasse*“ der RWTH Aachen University gefördert. Das Metaprojekt „*DemoScreen – Kommunikation, Kooperation und Innovationsfähigkeit im demografischen Wandel*“ des Förderschwerpunkts „Innovationsfähigkeit im demografischen Wandel“ wird durch das BMBF gefördert und vom Europäischen Sozialfonds (ESF) im Rahmen des Forschungs- und Entwicklungsprogramms „Arbeiten - Lernen - Kompetenzen entwickeln. Innovationsfähigkeit in einer modernen Arbeitswelt“ kofinanziert.

[9] Weiterführende Artikel zu den beschriebenen Forschungsansätzen finden sich in Jeschke et al. [18–20].

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# Scientific Cooperation Engineering in the Cluster of Excellence Integrative Production Technology for High-Wage Countries at RWTH Aachen University

**Claudia Jooß, Florian Welter, Ingo Leisten, Anja Richert, Anne Kathrin Schaar, André Calero Valdez, Eva-Maria Nick, Ulrich Prahl, Ulrich Jansen, Wolfgang Schulz, Martina Ziefle and Sabina Jeschke**

**Abstract** Interdisciplinary scientific cooperation plays a decisive role for the generation of new knowledge. The augmenting dynamic and complexity of scientific forms of cooperation require new approaches for interlinking people and knowledge from different disciplines to enable people for succeeding in interdisciplinary cooperation. Concerning the case of the cluster of excellence *Integrative Production Technology for High-Wage Countries* at RWTH Aachen University this challenge is addressed by cross sectional processes (CSP). CSP are supporting networking processes and strategic cluster development by means of learning and knowledge management. Through cross-sectional activities, a new method for knowledge and organizational development was identified – *scientific cooperation engineering*. It aspires to support the transfer of highly complex, dynamic and interdisciplinary research cooperation into sustainable and robust structures. The design of *scientific cooperation engineering* will be outlined in this position paper.

**Keywords** Knowledge and Cooperation Engineering · Interdisciplinary Innovation Management · Diversity Management · Performance Measurement

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## 1 Introduction

*Scientific cooperation engineering* depicts a new method enabling knowledge and organizational development for interdisciplinary clusters of excellence. The latter are part of the German excellence initiative[1]. The two main objectives of the case study – the cluster of excellence *Integrative Production Technology for High-Wage Countries* at RWTH Aachen University – are:

- the resolution of the polylemma of production[2] from a complexity and socio-technological perspective,
- and the design and operation of economically, ecologically and socially viable production systems in high-wage countries [1].

The research consortium of the cluster comprises 25 principal investigators/professors from five departments of RWTH Aachen University and associated institutes [1–3]. The fusion of different competences, knowledge, heterogeneous objectives of institutions and actors (e. g. professors, chief engineers or research assistants), a wide range of scientific experience as well as different cultures concerning scientific and operative working, are cluster-specific characteristics. Due to these characteristics, *scientific cooperation engineering* is implemented to interlink different research areas aiming at establishing sustainability concerning the aspects: people, science and structures.

## 2 Cluster-Specific Sections of Scientific Cooperation Engineering

Core activities of *scientific cooperation engineering* are generated from results of an accompanying research project in the first funding period of the examined cluster [3–5]. Here, a prototype model[3] was developed specifying design elements and cluster-specific measures for the management of cross sectional processes (CSP). The initiated measures are supporting the stabilization of the cluster of excellence and the efficiency of the scientific working processes. Within the accompanying

[1] The excellence initiative was started in 2005 by the government and federal states. It is divided into three funding lines: graduate schools, clusters of excellence and future concepts for top-level research.

[2] The resolution of the polylemma of production considers two dichotomies. The first dichotomy: scale and scope describes the contradiction between the realisation of a high variety of customised products and the cost-effective manufacturing of mass products. A second dichotomy exists between plan orientation (the objectives of lower-level entities are highly synchronised) and value orientation (highly dynamic production systems).

[3] The prototype model was composed by the synthesis of a literature analysis as well as an empirical approach triangulating cluster-specific data resulting from direct and indirect evaluations and structured interviews. This enabled the identification of tailor-made sections of *scientific cooperation engineering*.


**Fig. 1** Sections of scientific cooperation engineering in the cluster of excellence

research project of the prototype model e. g. one research question dealt with the challenge of high staff turnover. The latter has to be considered during the entire funding period.

Thus the overall objective of *scientific cooperation engineering* is to set up sustainable personnel and organizational structures for scientific cooperation leading to the super-ordinated research question [1]: *Which actions are necessary to support the transfer of highly complex, dynamic and interdisciplinary research cooperation of the cluster of excellence into sustainable and robust structures?* (cf. Fig. 1).

To cope with this challenge the following tailor-made sections of *scientific cooperation engineering* were identified for the cluster of excellence *Integrative Production Technology for High-Wage Countries*: knowledge and cooperation engineering, interdisciplinary innovation management, diversity management and performance measurement (cf. Fig. 1).

## *2.1 Knowledge and Cooperation Engineering*

**Knowledge and cooperation engineering comprises the interaction of data, information and knowledge on all organizational levels to support sustainable personnel and organizational structures.**

Knowledge and cooperation engineering refers to engineering methods e. g. originating from product development, service engineering and user centered design to develop tailor-made measures by integrating the cluster-specific end users in an iterative manner. The section addresses the scientific elaboration of knowledge retrieval concepts as well as the development of automated knowledge retrieval processes and ontology-based tools. This e. g. includes web-based knowledge maps to promote a multiple and digital form of scientific interlinking and to reduce individual efforts for searching cluster-specific information. The initiation and editorial assistance of a cybernetic cluster method suite (containing all cluster-internal methods used) as well as the implementation of approaches supporting the definition of common terminologies like an interactive glossary will be developed. Moreover, the conception and organization of e. g. cluster-specific colloquia and strategy workshops – partly opened for external stakeholders – will be executed. To collect and exchange interdisciplinary knowledge, standardized methods will be implemented and evaluated as cluster-wide tools. One of the first tools to be implemented is based on a *Flow-Chart* approach combined with a small set of *Research Questions* orientated on the specific problem.

## *2.2 Interdisciplinary Innovation Management*

**Interdisciplinary innovation management measures, visualizes and manages the integration of experts from different scientific cultures and disciplines within the cluster.**

Therefore the trade-off between disciplinary and interdisciplinary excellence has to be balanced. In order to promote and support possible synergetic opportunities, collaboration interfaces of actors have to be identified. With a qualitative and quantitative method suite participant positioning, publication strategy as well as disciplinary and interdisciplinary method competence and composition are individually determined, abstracted and generalized and integrated into an adaptive interactive model of the cluster's configuration and performance. In order to generate findings from this model and provide customized feedback a visualization suite is constructed. Thereby rules of successful interdisciplinary cooperation are derived and fused into a set of interactive interventions, such as method trainings, interdisciplinary publication workshops and change of perspective seminars. This process will converge into the so-called interdisciplinary school of methods addressing research-, communication- as well as cognitive methods. The interdisciplinary school of methods focuses on cybernetics as an overall methodological approach of all scientific partners within the cluster. Seminars will be offered for different groups of actors in dependence of their respective level of experience. They will focus on operative skills for working in interdisciplinary environments, scientific methods for researching and publishing in interdisciplinary environments as well as cybernetic methods to expand the high quality of scientific cluster outcome.

## *2.3 Diversity Management*

**Diversity implies the terms age, gender and culture. It aspires to establish diversity as a source of innovation and a measurable and utilizable competitive factor for science and production.**

The successful development of interdisciplinary solutions is supported by a high level of heterogeneity concerning the actors and institutions involved in the cluster. Therefore a fundamental new understanding of the product and production technology linkages of the stakeholders involved is necessary. Whereas diversity was defined by aspects like age and gender in the first funding period, the CSP expand the term diversity management with the aspect of culture in scientific teams. Within the cluster of excellence, researchers from different countries and with various scientific backgrounds need to be supported enabling a level of debating and strategy to succeed. An empirical study will be designed to evaluate the performance of these multinational and interdisciplinary teams. Based on publications from the first funding period, the influence of mixed cultural and professional teams on the manner of publication is to be analyzed. A subsequent expansion of the study to other clusters and major research facilities is imaginable. The results shall serve to recommend methods for performance measurement and optimization in international task groups and thus install diversity as source of innovation and measurable and utilizable competitive factor for science and production.

## 2.4 *Performance Measurement*

**Performance measurement aspires to contribute to steering and regulation the integrative research processes and outputs in order to support sustainable cluster structures.**

Preliminary, performance depicts the consequence of efficient and effective actions on all service and decision-making levels of an organization to satisfy plural interests concerning multidimensional objectives such as finances, quality or processes [6]. Additionally, it concerns the quality of benefits for stakeholders [7]. Performance measurement constitutes a process of quantifying efficiency and effectiveness of an action [8]. In the context of scientific cooperation engineering, performance measurement aims to support the management, steering and regulation of highly complex scientific cooperation. Thus far, the implemented prototype of the cluster-specific prototype aspires that this goal can be achieved by three approaches:

- a cluster-specific Balanced Scorecard for cluster-internal performance measurement [9],
- a benchmarking approach for cluster-external performance measurement [7]
- and the development of methods and concepts analyzing quantity and growth of intellectual capital and knowledge gaps within the cluster of excellence [10].

The iterative development of the three approaches will complement the previous prototype. It is aspired to culminate this into an integrated strategy planning tool facilitating an advanced management of the entire cluster of excellence in future.

## 3 Outlook

Scientific cooperation engineering contributes to the resolution of the polylemma of production by interlinking people and knowledge from different disciplines to enable people for succeeding in interdisciplinary cooperation. The next step of *scientific cooperation engineering* is to initiate a further development considering the main principals of cybernetics [1, 11]. To support sustainable and robust structures the approach of *scientific cooperation engineering* will also face the challenge of transfer to other clusters of excellence and comparable forms of collaborative research, bearing in mind that a combination of generic and tailor-made elements is necessary.

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# Technological Changes in High Reliability Organization: Implementation of a Telematic Rescue Assistance System into German Emergency Medical Services

**Marie-Thérèse Schneiders, Daniel Schilberg, Ingrid Isenhardt and Sabina Jeschke**

**Abstract** The introduction of a Telematic Rescue Assistance System into the German Emergency Medical Services aims at the enhancement of treatment quality and efficiency of rescue operations. Rescue teams are supported on site by a specialized emergency physician in a remote Competence Centre. Using mobile radio networks the Telematic Rescue Assistance System enables real time transmission of voice communication, vital parameters, pictures and videos from any emergency site. The successful and sustainable operation of a Telematic Rescue Assistance System in German Emergency Medical Services organizations requires the elaboration of a context and object adjusted implementation strategy. Dealing with technology change in a so called High Reliability Organization, organizational culture and structure affect primarily the design of available implementation instruments. Further requirements to the arrangement of an implementation process result from the sociotechnical specificities of the Telematic Rescue Assistance System. The present work presents the methodology used within the research project to develop an adequate implementation strategy, pointing out the relevant requirements and the chosen instruments to implement the system within five different Emergency Medical Services departments in 2012.

**Keywords** Telematic Rescue Assistance System · German Emergency Medical Services · High Reliabilty Organizations · Technology Implementation · Implementation Management

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## 1 Introduction

Within the German research project Med-on-@ix (2007-2010) engineers, researchers and physicians from Aachen developed a preliminary model of the *Telematic Rescue Assistance Systems* (TRAS) and evaluated the prototype for 10 months within a trial run in the *Emergency Medical Services* (EMS) of the city of Aachen. The evaluation of the system revealed the potential of telemedical support during EMS missions regarding high quality treatment of emergency patients and the enhancement of information and time management.

The TRAS allows the immediate support by EMS teams during an emergency operation by a tele-EMS physician in a remote *Competence Center* (CompC). Not only the real-time transmission of vital data and pictures from the emergency site but also the video footage out of the *Mobile Intensive Care Unit* (MICU) via 3G mobile radio networks, provide the necessary information basis for the qualified telemedical support. Via mobile communication the tele-EMS physician is connected with the team on site and provides the necessary medical know-how and decision authority in terms of adequate diagnosis and treatment. The CompC serves as an information crosspoint between prehospital, clinical and related health care facilities along the medical supply chain [1].

The project work pursued a joint organizational and technical development approach [2] to guarantee a user-centered requirement management and a continuous process improvement in line with the development. The constant involvement of EMS physicians and paramedics into the design and development process as well as trials at different levels of development (simulation studies in 2008 and 2009) and the final trial run in regular operations of the fire department in Aachen aimed at a wide scope of requirements regarding the implementation of the TRAS in German EMS organizations.

The follow-up project "TemRas – Telemedical Rescue Assistance System" started in 2010 faces the challenge to establish the TRAS at a broader level to be used in five different EMS departments in Western Germany. The research action is funded by the Ministry of Innovation, Science and Research of the state of North-Rhine Westphalia (MIWF) and the European Union for 3 years. At a technical level the roll-out of the TRAS requires the adaption of the software architecture to enable simultaneous support of multiple MICUs. The adapted software architecture overcomes the absence of standards for data exchange, integrates the existing devices used by MICUs and manages the communication for different applications [3]. The telematic network connects the MICU, the EMS team on site and the CompC. The long distance communication is based on 3G mobile networks. Bluetooth and wireless transmission both enable the real time data transmission in the near area from the monitor/defibrillator unit, a Bluetooth stethoscope and a digital camera as well as a video life stream from a network camera in the MICU to the CompC (Fig. 1).

Besides the technical optimization of the TRAS, the main challenge is the implementation of the system in rural and urban areas with heterogeneous initial conditions in terms of resources, operating standards as well as user groups with different level of qualification and motivation.

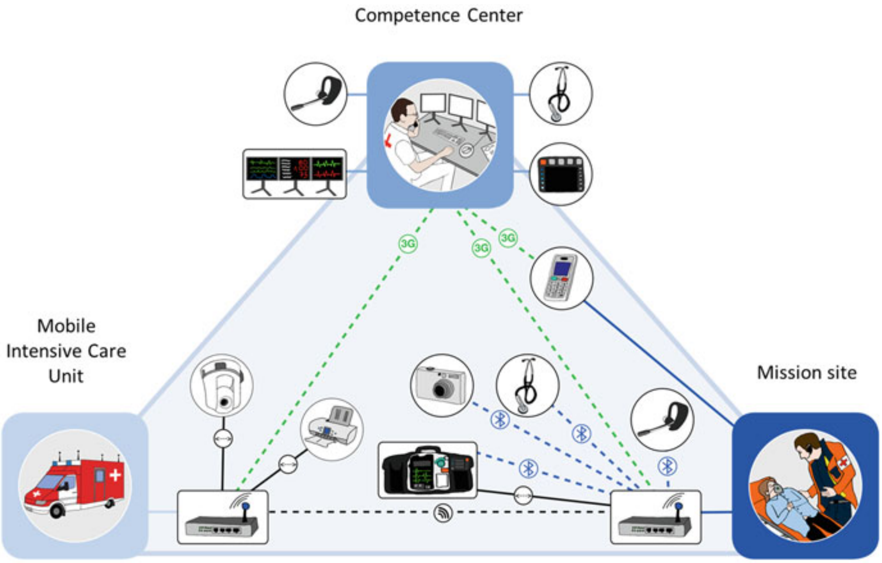


**Fig. 1** The optimised telematic rescue assistance system

The use of the TRAS implies a perceptible impact on communication structures and team processes [2]. Therefore the introduction into EMS organizations requires an implementation strategy considering system-related requirements as modified working processes, new working environments and new equipment. Furthermore organization-related requirements have to be considered to design the necessary actions. The implementation context is characterized by existing working conditions, cultural specification of the organization and structural conditions of the EMS department.

This paper offers an insight into the design of the implementation strategy pursued in the project TemRas. Starting with a literature review on the state of the art (Sect. 2), Sect. 3 offers an insight into the characteristics of EMS as target organization of technology change. The methodology presented in Sect. 4 is partly borrowed from sociological and management theories. Whether sociological technology acceptance models underline the necessity of participatory implementation approaches, economical and marketing methods turn the gaze on the possibilities to bring about the organizational adoption and the long-term use of new technologies. Based on empirical values from the final evaluation results of the former project and scientific findings about EMS as a High Reliability Organization (HRO), an implementation strategy is developed relying on organization-related and object-related requirements (Sect. 5). The paper finally concludes with the idea how to learn from high reliability theory to design successful implementation processes.

## 2 State of the Art

To achieve the intended results by introducing new technologies a careful design of the implementation process is almost as relevant as the system design itself [4]. Since the decision to adopt a new technology does not online depend on the character of the product but goes in line with the first impression of its usefulness and the measures aiming at familiarizing the user with the changed working processes. The proper use of telemedical applications and the embedment into approved working routines affect the dissemination of the innovation through the healthcare sector. The aim of implementing telemedicine into healthcare organizations is to generate improved working processes with recourse to telemedical assistance. Care organizations develop routines around the use of new technologies and thereby create a selfreinforcing cycle of stability [4].

Following Gersick and Hackman routines are “functionally similar pattern of behavior in a given stimulus situation without explicitly selecting it over alternative ways of behaving” [5]. Current organizational routines can therefore be a source of organizational resistance against implementation of new technology combined with unknown working procedures.

Although past research has discovered that the decision to adopt a new technology does not guarantee its successful implementation [6] there has been only a few empirical studies on how to manage the group and interpersonal process to make implementation happen [7]. The organization’s willingness to adopt a new technology is a basic condition for successful implementation depending besides the user acceptance on the attitudes of managers towards technological change [8]. Research on technology acceptance revealed the necessity to consider not only the decision to adopt as a punctual event but to make a distinction between the classical terms of attitude, adoption or diffusion. Kollmann [9] recommends a gradual construct of acceptance considering user attitudes in a first phase, the willingness to try out a technology and in the end the long-term incorporation of a technology into organizational routines. Implementation measures aim at the creation of new organizational routines around the technology use, requiring a positive attitude and the readiness to try out something new. The success of the implementation process thus depends on the creating positive acceptance from the first user contact on. The closeness to the organizational environment encourages the consideration of cultural and structural particularities of the target organization.

Studies on adoption of new technologies in healthcare organizations underpin that technology implementation is a process during which new beliefs, new skills, and new collaborative routines are simultaneously developed [7]. Edmonson et al. [7] found out that “organizational differences in size, resources, academic status, innovation history, and senior management support were not primarily associated with implementation success” but ascribe these results to the unusual degree of homogeneity across the observed cardiac surgery departments, introducing minimal invasive cardiac surgery. The authors point out the importance of collective learning processes and the role of team leaders as innovation drivers. It is decisive to foster open communication and mutual trust within the teams, "reinforcing a particular technological frame, which affects how others think about a new technology and the nature of the challenge it presents" [7]. Edmonson et al. [7] suggest a four-step process to establish new working routines: enrollment, preparation, trials, and reflection. The process model that emerged from these data is mundane: (1) carefully select a team, (2) practice and communicate, (3) work to encourage communication while experimenting with new behaviors in trials, and (4) take time to reflect collectively on how trials are going so that appropriate changes can be made [7].

Similar studies and observations in EMS organizations have not yet been carried out. The remarks made so far show the necessity to take a closer look at the organizational culture to design an implementation strategy, along with stimulating of positive technology acceptance as a prerequisite for organizational adoption.

## 3 Technology Change in High Reliability Organizations

As EMS teams are able to balance effectiveness and safety despite the complexities of the environment regarding uncertainty of the situation, time pressure and restricted available resources, EMS organizations are considered High Reliability Organizations (HRO). Risky environment and the fact of facing partly insoluble tasks make human errors practically inevitable in these organizations; nevertheless fewer mistakes are made than expected, as problems are identified at an early stage. These organizations do this by consistently noticing the unexpected and reacting in a very flexible way.

Following the HRO model by Weick and Sutcliffe [10] these organizations have a collective state of mindfulness in common. Five principles of acting and organizing create a mindful way of behaving:

1. preoccupation with failures rather than successes,
2. reluctance to simplify interpretations,
3. sensitivity to operations,
4. commitment to resilience and
5. deference to expertise.

Members of mindful organizations pay attention to small deviations from regular operations and consider even small failures as a potential cause for bigger problems. They do not try to overlook mistakes to focus on successes but take failures as learning moments. HRO avoid the human tendency to oversimplify the world around us. In order to create more varied and differentiated expectations of what could happen HRO build diverse teams and welcome a wide variety of perspectives that challenge the conventional wisdom.

The concentration on things that disconfirm, are uncertain or implicit creates a so called "mindful culture" [11] that Weick describes as an informed culture creating and sustaining continuously intelligent wariness. A mindful organization culture

| | person-related objectives | object-related objectives | | |
|---|---|---|---|---|
| | user-acceptance | quality | cost | time |
| result-oriented | high acceptance for the TRAS | compatibility between the TRAS and the EMS organization | low follow-up costs | early introduction |
| process-oriented | high acceptance for the implementation process of the TRAS | fault-free approach, little impairment of day-to-day business | Low implementation costs | short duration of implementation |

**Fig. 2** Objectives of the implementation activities

provides a basic framework for the capability to discover and to manage unexpected events, to create high reliability.

Paulina and Callois [12] showed by analyzing reliability strategies in the military, space and semiconductor industries that HRO tend to limit their speed of technological innovation in order to preserve their level of reliability. LaPorte [13] explains this phenomena with the risky environment in which HRO operate "in wich any change in circumstances, internal processes or technical innovation is more likely to degrade than to improve existing operations". These assumptions have so far not been transferred to the analysis of EMS organizations; however no successfully realized widespread innovations in EMS are observable within the last decades.

## 4 Methodology – Development of a Implementation Concept

Contrary to the traditionally interpretation of the implementation as a closed stage of development within a engineering process, current approaches dealing most with strategy implementation processes foster a new point of view. Instead of splitting the development process into a planning, an implementation and an evaluation phase, implementation activities refer to change tasks realized at different stages of development. Daniel [14] defines implementation as all activities that ensure the future success of the application deployment object in the implementation context, regardless in which phase of the development the corresponding activities take place. Those activities target both person- and object-related objectives concerning then the two reference planes 'result-related objectives' and 'process objectives'. Figure 2 shows the defined objectives in line with the implementation of the TRAS.

Beside the positive user acceptance in view of an organizational adoption of the system, best quality of the TRAS and the implementation process as well as an early and brief introduction of the TRAS is intended.

To achieve the defined context- and object-objectives (Fig. 2) requirements towards a successful implementation strategy were identified on both sides by referring scientific findings from the project itself and external theoretical and empirical research work.

Context-oriented implementation is focusing primarily on overcoming personnel and organizational barriers of implementation. Approved instruments originate from the categories information, qualification, motivation and organization [15]. Applied measures concerning these categories can have cross-sectional effects such as informational and qualifying measures can have motivational impact on the target group. The success of all implementation measures depends on the acceptance by the affected persons and their willingness to take part in the change process. In this regard information and communication actions have a direct link to technology acceptance.

As Chau and Hu [16] showed in their study upon telemedicine acceptance by physicians the main task of management in technology change process consists in demonstrating and communicating the technology's usefulness to the routine tasks and services [16]. To avoid the so called "Not invented here" syndrome [17] the design of the TRAS has to fully recognize the needs of the user groups. The early involvement of paramedics and physician into the development process had the most important impact on the user acceptance. The consequent dialog and the constructive way of dealing with feedbacks, fears and inhibitions paved the way to a user-centered technology creation.

Object-related requirements were derived from several evaluations of the previous project Med-on@ix. The use of the TRAS was evaluated during a 1-year trail from different perspectives. Besides the quality of treatment, focusing on time management and the appropriateness of the treatment process, the user acceptance of the TRAS was evaluated to gather potential for improvement of the system. By analyzing the impact of the TRAS on working routines of EMS teams several requirements were identified aiming at the elaboration of working and communication rules to be considered in telemedically supported missions [18]. Change tasks where identified concerning the use of checklists to guarantee a necessary level of standardized working procedures and the training of users in using the TRAS properly.

Bergrath et al. [19] evaluated the technical and organizational feasibility of the pilot TRAS based on 157 EMS missions in the city of Aachen, concluding that the use of the TRAS is feasible even if technical reliability and availability has to be improved in the future. The authors reported technical problems caused by network disconnections especially inside buildings. Evaluation of organizational implementation revealed successful cooperation between the EMS team on site and the tele-EMS physician in terms of ECG interpretation, diagnosis and treatment decisions.

To achieve the implementation objectives (Fig. 2) context and technology related requirements are describe in the following section and the implementation strategy is drawn to meet cultural and structural particularities of the implementation project.

| dimensions of the implementation strategy | | | design options | | | |
|---|---|---|---|---|---|---|
| culture | behavioural style | | top-down | | bottom-up | |
| culture | managerial style | | directive | | participatory | |
| structure | object | Extent of implementation | Complete object | | Gradual introduction of object modules | |
| structure | object | Stage of development | Ideal solution | | Approximate solution with rework option | |
| structure | context | context definition | overall context | | successive introduction into context areas | |
| structure | context | transition between context areas | coupled | overlapping | parallel | decoupled |
| structure | time | Point in time | Considering the relevant maturity level | | Considering favorable opportunities | |

**Fig. 3** Development of an implementation strategy

The morphological box in (Fig. 3). modeled after Baumgartner and Schneeberger [20] offers an insight into the range of strategic design parameters.

The implementation of the chosen strategy is finally realized through different implementation measures. As mentioned above implementation instruments belong to the categories information, qualification, motivation and organization.

# 5 Results – The Implementation Strategy

## *5.1 Organization-related Requirements*

The implementation of new technologies into German EMS organizations underlies the barriers of the federal healthcare system. State specific EMS legislations bring about different structures of service, working practices, level of qualification and various allocations of rights and duties. The introduction of technological assisted working procedures has therefore to meet shared needs of EMS organizations, avoiding conflicts with structural conditions by adapting the TRAS at the prevailing conditions. As for example the training of paramedics is integrated into weekly standard on-the-job training. For same reasons the application of the TRAS does not explicitly interfere in the handling of emergency calls and the working processes of the dispatch center for rescue services.

As the impact of the TRAS is particularly connected to the performance of teams on site, the implementation efforts focused the operational capability. The TRAS has to be easily integrated as an add-on solution to regular operational processes. The evaluation of the Med-on-@ix System by paramedics showed the necessity to accompany the introduction of the TRAS by intensive training to generate qualified working routines in view of failure-free communication and teamwork processes. Users pointed out the importance of open communication and feedback possibilities. Regular debriefings and feedback between the users on site and the tele-EMS physicians constitute further important implementation measures.

Besides the importance of teamwork and open discussions for HRO [21, 22], strong internal leadership is accounted within the implementation process by an elaborated role concept regarding both the operation of the TRAS during emergency missions and the implementation process itself realized by the project team. The implementation of the TRAS requires the support by authorities to foster the dissemination and consequent use of the new technology by the whole organization. Therefore the pre-information of authorities and the participatory design of the organizational implementation are decisive. Research findings about HRO [23] bring about further requirements to be considered:

- well-defined project objectives
- target-orientation within the project
- team-orientation
- definition of roles

### 5.2 *Object-related Requirements*

The development of the TRAS as a sociotechnical system faces beside technological challenges particularly many organizational challenges, critical in view of a successful implementation of the TRAS into daily work of EMS. The implementation builds on a joint technical and organizational development [2] aiming at an optimized user-centered design of the technical system as well as the organizational concept enabling the operation of the TRAS. The design of the TRAS requires the consequent adaption of the system upon the organizational conditions of use. The modular architecture of the system offers the possibility to implement different functionalities and various complexity levels, enabling an organization specific implementation effort.

The scope of the implementation constitutes a more challenging characteristique of the implementation object. On the one hand various divisions of the EMS department as well as the dispatch center, municipal administration and clinic workers are involved into the change project. On the other hand the involved paramedics and physicians have different needs, qualifications and levels of technical affinity.

The use of the TRAS implies beside specific organizational procedures, legal regulations concerning the delegation of medical treatment and technical complexity. In the consequence the implementation of the TRAS is confronted with a difficult communicability. In combination with the necessity of training mentioned above the implementation requires extensive measures of preparation.

Bergrath et al. [19] showed the failure-free use of the TRAS depends on the reliability of mobile radio networks. As these technologies remain instable inside buildings and in rural areas and as the context of use requires high reliability the implementation of such a system has to be realized as an add-on to traditional EMS working procedures.

### *5.3 Implementation Strategy*

Analyzing the described requirements success criteria for the adoption of a TRAS can be derived. Information and communication instruments avoid misunderstanding and miscommunication about the implementation project. It is therefore decisive to look for an early opportunity to inform the members of the organization. Starting with a roadshow in every EMS department with possibilities for an open discussion, regular meetings in line with training units and feedback meetings scheduled along with the TRAS operation.

By identifying promoters of the implementation project at various hierarchy levels and within the different involved divisions of the EMS organization the information flow and the diffusion of the TRAS within the implementation context is raised. To gather current moods or hidden rumors internal contact persons act as mediators and opinion-formers to intensify the harmonization between user needs and system design. Thereby the designated mediators play an important role in fostering positive user acceptance, reporting everyday experiences with the system to the system developers.

Referring to Fig. 3, the main design elements of the developed implementation strategy are showed in Fig. 4.

The chosen strategy to implement a TRAS into a German EMS organization is characterized primarily on a cultural level by a top down strategy concerning the initialization of the implementation project. Authorities of the EMS department and municipal administration have to drive the adoption by legitimating the use of the TRAS in regular operations.

As the decision to adopt the technology is first of all taken on a team level several measures have to be taken to encourage the involvement of paramedics and physicians as primary user groups. The participatory approach is realized through feedback and communicative instruments. By the involvement of users into the development of technical and organizational system components user acceptance is achieved and a common goal comprehension is generated through consequent dialogue. The latter fosters in combination with extensive training on the job the mindful culture needed to achieve high reliability.

The extent of implementation is defined by the modular character of the TRAS. The gradual introduction of system components reduces the complexity of the implementation. To foster the user involvement regarding the adjustment of the system

| dimensions of the implementation strategy | | | design options | | | |
|---|---|---|---|---|---|---|
| culture | behavioural style | | top-down ↔ | | bottom-up | |
| culture | managerial style | | directive ↔ | | participatory | |
| structure | object | Extent of implementation | Complete object | | Gradual introduction of object modules | |
| structure | object | Stage of development | Ideal solution | | Approximate solution with rework option | |
| structure | context | context definition | overall context | | successive introduction into context areas | |
| structure | context | transition between context areas | coupled | overlapping | parallel | decoupled |
| structure | time | Point in time | Considering the relevant maturity level | | Considering favorable opportunities | |

**Fig. 4** Implementation strategy for the introduction of a TRAS

the TRAS is initially operated within a small team of users or rather by running only one equipped MICU.

As the TRAS is used within a heterogenic flied of applications facing different infrastructural conditions the system is based on a modular architecture facilitating the implementation of approximate solution with rework options. Furthermore the implementation is relieved by the stepwise extension of the user group. The involvement of selected EMS teams at a first level of the roll-out stimulates the organizational adoption.

The TRAS is implemented as an add-on solution for EMS missions. The parallel running of the traditional and the innovative way of treatment underpin the fall-back character of the tele-EMS physician. The implementation of the TRAS aims at reducing the time period when no EMS physician is available on site. To reduce the procurement costs the implementation date is matched with the tendering of new MICU by the EMS departments. Considering these favorable opportunities the necessary conversion work is combined with the regular construction of the MICU.

## 6 Conclusion and Outlook

The successful use of a TRAS in EMS missions requires an elaborated implementation approach starting already in the first development phase. Implementation research offers several starting point to successful technology introduction, lacking at the same time of practicable models to elaborate an implementation project.

The present paper suggests a methodology to design a context and object oriented implementation strategy. We pointed out the importance of user involvement within the design of organizational and technical aspects of the TRAS to gain the necessary acceptance and finally to reach the organizational adoption. Regarding the here considered use case, the characteristics of an EMS organization as a HRO play a significant role in the choice of implementation instruments. Learning from HRO theories we considered organizational conditions producing high reliability into the technology change strategy.

As information technology is more and more adopted within the healthcare sector research on best practice implementation projects are needed to foster the capacity for innovation also in prehospital healthcare organizations. Current research activities might take into account the importance of planned implementation to achieve marketable technical innovations. Furthermore the scientific discourse on learning from high reliability organizations to design efficient and well-accepted technology changes might radiate on various interdisciplinary research areas.

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# Further Development of a Performance Measurement Approach in a Research Cluster of Excellence

**Stefan Schröder, Claudia Jooß, Anja Richert and Ingrid Isenhardt**

**Abstract** In June 2012 the further funding of the research cluster of excellence (CoE) "Tailor-Made Fuels from Biomass" (TMFB) at RWTH Aachen University (2012–2017) was announced by the German Research Foundation (DFG) and the German Council of Science and Humanities. In this context the Supplementary Cluster Activities (SCA) within the CoE were enlarged to expend the promotion of an effective and efficient cross linking of CoE members by means of knowledge engineering and knowledge transfer, such as the determination and measurement of cluster-specific key performance indicators.

Overall, the SCA aspire to ensure the high quality of research by measuring and evaluating the performance of the cluster. Therefore inter alia in the first funding period a cluster-specific Balanced Scorecard was implemented and regularly adapted for the requirements of the cluster. This yearly evaluation rather deals with performance measurement on a meta level, admits a cluster wide overview of research level and gives recommendations of action to the cluster management. The augmenting dynamic and complexity of scientific forms of cooperation require new approaches for interlinking people and knowledge from different disciplines to enable people for succeeding in interdisciplinary cooperation and in general lead the CoE-"TMFB" to success.

Preliminary studies, e. g. empirical analyzes as well as recommendations of the German Council of Science and Humanities, offer further valuable clues to relevant indicators of scientific processes such as in CoE-"TMFB". Here the combination of quantitative and qualitative parameters is discussed to measure performance in a complex cluster. Therefore the further development of performance measurement in the second funding period will establish an advanced performance measurement approach which supplements the contemporary cluster-specific Balanced Scorecard and target interdisciplinary performance comparison on sub-project (micro) level. For this purpose it is necessary to analyze and operationalize the requirements i. e. of the management, industrial partners or the research funding organizations. More importantly thematic key aspects such as output, interdisziplinarity, international presence, impact of the cluster as a system and internal process enhancement have

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to be considered and integrated. This new approach will operate parallel to the BSC and supplement the contemporary evaluation approach.

While measuring the degree of target achievement is supposed to be more relevant in DFG-audits, the quality of internal, interdisciplinary processes is an important indicator of cluster-internal target achievement, too. The improvement of the quality of processes will be supported by the investigation of potential for optimization and efficient cross-linking of the CoE members. This aspires a more efficient use of resources parallel to a continuously high quality of research results. The vision of SCA is to foster interdisciplinary exchange and a continuous comparison of research achievements of the CoE in accordance with the overall vision of the cluster and the DFG performance criteria.

**Keywords** Knowledge Management · Performance Measurement · Controlling · Quality Management · Cooperation in Big Research Cluster · Supplementary Cluster Activities (SCA)

## 1 Introduction

Performance measurement and management are common in profit organizations to increase output and foster transparency in achieving objectives. The adaption of those concepts in an interdisciplinary scientific environment depicts new challenges for promoters and scientific managers [1]. This is caused by a high complexity and dynamic progression which requires new forms of management [2].

In the last decade, evaluation, rating and the application of performance measurement systems have increased in research structures [3, 4]. Proven concepts – mostly derived from profit organizations – have been adapted. Thereby it was pointed out that these systems play an important role on different levels of aggregation, e. g. within strategic planning and regulation of CoE [3]. Inevitably in a whole system CoE, performance, interdisciplinary cooperation and the quality of research processes must be enhanced also on sub-system level.

The purpose of this paper is to emphasize the necessity of (further) performance measurement tools, either as an extension or a supplementation. A detailed research approach for scientific forms of organizations like CoE-"TMFB" in the second funding period is given. This approach shall work steadily, partly automated and give individual recommendations of action to the CoE-actors.

## 2 Object of Research: The Cluster of Excellence Tailor-Made Fuels from Biomass

The second funding period of the CoE "Tailor-Made Fuels from Biomass" at RWTH Aachen University was announced by the DFG and German Council of Science and Humanities in June 2012. The CoE-"TMFB" adopts an interdisciplinary approach, through the application of optimized synthesis processes, towards research

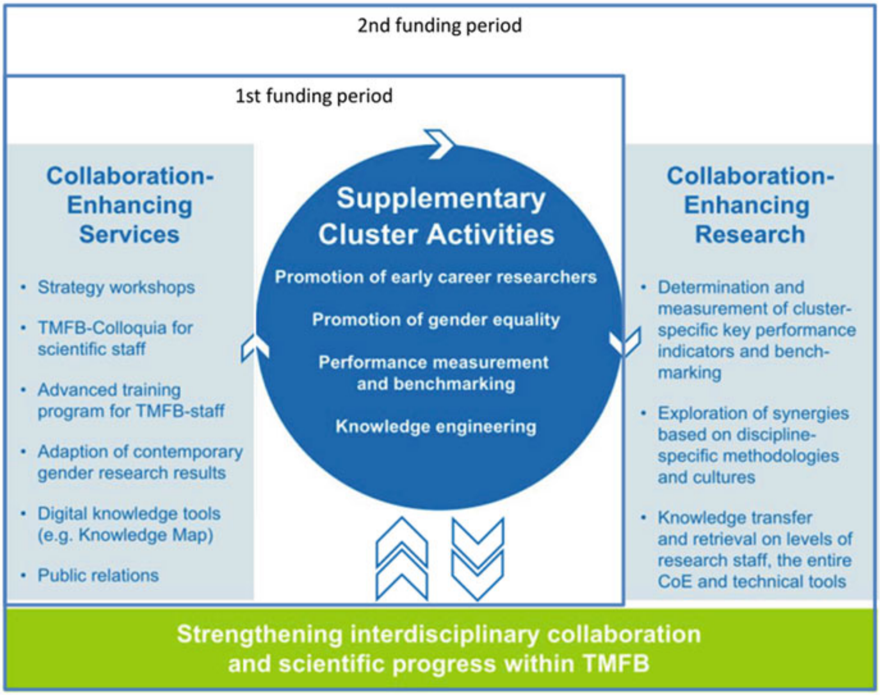


**Fig. 1** Organization of the SCA in the CoE-"TMFB" [5]

of new, biomass-based synthetic fuels, in order to verify their potential, with regard to modern combustion technologies, while simultaneously reducing the dependence on fossil fuels [5]. The long-term 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 [6].

As part of the CoE-"TMFB" the Supplementary Cluster Activities were enlarged to promote an effective and efficient cross linking of CoE members. The activities of the SCA during the first funding period (2007–2012) mainly focused on the promotion of early career researchers, promotion of gender equality, performance measurement and benchmarking as well as knowledge engineering.

These approaches include Collaboration-Enhancing Services (CE-Services), which comprise strategy workshops, colloquia, trainings and public relations. By means of strengthening interdisciplinary collaboration, SCA were enlarged in the second funding period by Collaboration-Enhancing Research (CE-Research) (c.f. Fig. 1).

In this context, synergies of discipline-specific methodologies and cultures are explored as well as knowledge transfer and retrieval is researched. As part of research, cluster-specific key performance indicators will be developed and an advanced performance measurement system will be realized and implemented to support the high

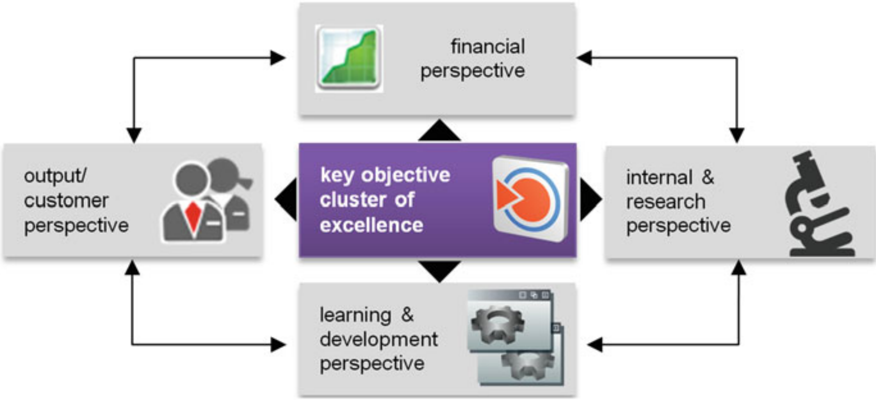


**Fig. 2** Four perspectives of the cluster-specific balanced scoreboard

quality of research. Thereby a strong interdependence between CE-Services and CE-Research exists in terms of iteration-loops. Insights according to the CE-Research advect into CE-Services and thus lead to continuous improvement processes (also the BSC control loop – c.f. Fig. 3 follows this feedback principle).

## 3 Proven Concept: The Balanced Scorecard

In the first funding period, steering and regulating of "TMFB" as a system with knowledge-intensive, interdisciplinary research structures became possible [7, 8]. In order to support the cluster management, a specific form of a BSC (based on Kaplan and Norton) was implemented. As one of different feasible performance measurement approaches the BSC was chosen because of its flexibility and adaptability [9]. Thereby the BSC meets the requirements of CoEs by considering their complexity and dynamic, focusing on strategies, fostering objective- and results-transparency and overarching communication. Therefore inter alia in the first funding period a cluster-specific Balanced Scorecard was implemented and regularly adapted for the requirements of the cluster.

With this tool, objectives of the CoE are improved and the cross-hierarchical communication and cooperation is promoted [10]. Thereby the BSC is adapted to the needs of the CoE as a measurement system for performance. This approach is characterized by the measurement and comparison of performance indicators on various levels (level of management and level of employees) and is based on a survey among all CoE- employees that is used for the evaluation of the cluster performance [11]. As shown in figure two, the cluster-specific BSC comprises four perspectives: internal perspective & research cooperation, perspective on learning and development, output/client perspective and financial perspective (Fig. 2).

According to the primary BSC of Kaplan and Norton, the BSC for "TMFB" possesses these perspectives which are necessary to create sub-targets [12]. Because

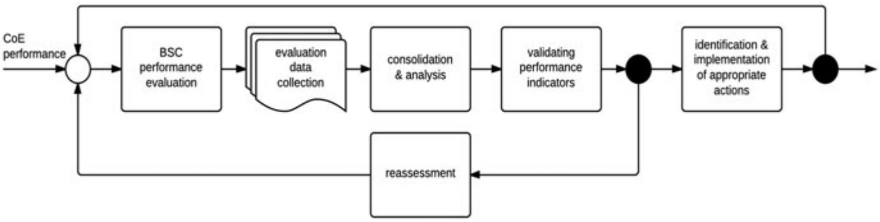


**Fig. 3** Balanced Scoreboard specific control loop

of the highly complex and dynamic research environment of "TMFB", the BSC is adapted to the CoE specific needs and for that reason the BSC is not completely congruent with the perspectives named by Kaplan and Norton. One perspective, the *output/customer* perspective, includes sub-targets such as the need of research results for further clients or associations (e. g. society or/and economy). Also, the generation of positive side effects or derived products for the research location of Aachen (e. g. image of the RWTH Aachen University) is operationalized and defined as a sub-target. Another perspective, the *internal & research perspective*, aims onto supporting a strong and productive cooperation among the staff of the cluster. Identifying and supporting different lines of communication between and for all actors in "TMFB" is targeted within this perspective. Moreover at this the way of scientific exchange and its challenges (in the context of interdisciplinary, heterogeneous teams) within the cluster are explored. Objective of the *learning & development perspective* is the promotion of all employees within "TMFB". Finally the financial perspective focusses inter alia on questions concerning the working time of the "TMFB" researchers.

Furthermore, the BSC works on a specific control loop. This control loop is developed and based on the basic pattern by Grote and Feldhusen which is able to describe socio-technique systems [13]. The abstracted and simplified control loop (c.f. Fig. 3) focusses on increasing the CoE performance with the aid of an electronically questionnaire and different statistical data analysis, which are described following.

Important components of the control loop are continual feedback-loops in order to reassess the Balanced Scorecard and thus continuous adapt the BSC to the cluster specific needs. Groundwork of this control loop is the yearly evaluation data. Till now the BSC was implemented three years in a row (2009–2011) and actually in the year 2013 (in the year 2012 the BSC was exposed due to the extension within the frame of the second funding period). Data was collected by a half-standardized electronically questionnaire among the "TMFB" staff, which was separated in two groups: Professors, Principle Investigators, Management and young researchers on the one hand, and research assistants on the other hand. Operationalizing performance indicators was done in reconcilement with the CoE management, further more referring to the goals and vision of the CoE depicted in the proposal and also derived from the DFG evaluation criteria [5, 6, 14, 15]. The operationalized performance indicators were

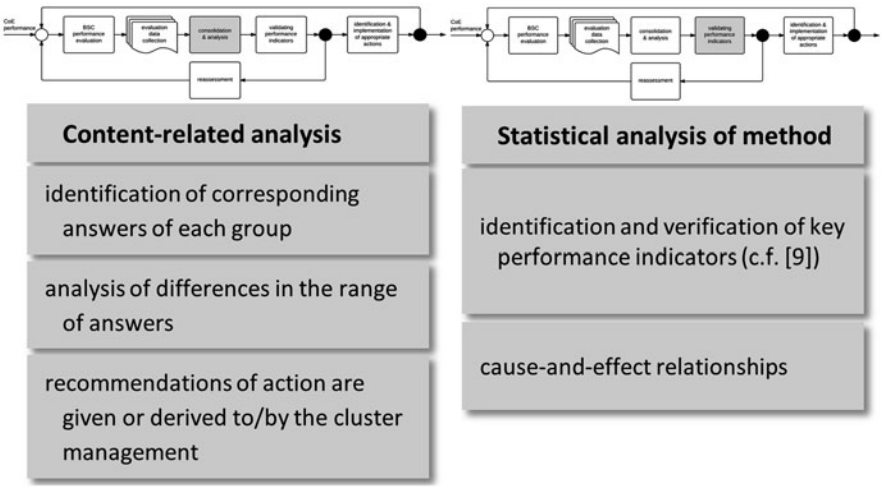


**Fig. 4** Performance measurement analysis. [9] = [9]

ranged from 1 = 'positive answer' up to 5 = 'negative answer'. The scaled answers by the two groups can be compared by a statistical approach. Average values and median are calculated to identify corresponding answers of each group. Furthermore, the standard deviation is calculated to analyze differences in the range of answers, as well as qualitative remarks could be given to supplement a holistic approach. On this basis the results of data were discussed and thereupon recommendations of action were developed in close collaboration with the cluster management (e. g. core-team).

In addition to content-related analysis, statistical analysis on the method was done, too. In this context Welter [9] analyzed indicators to identify key performance indicators by two statistical methods: firstly, all variables were calculated by using Spearman's rank correlation coefficient. Secondly, the amounts of correlation pairs per indicator were compared to verify the results. Indicators, whose size effects were $>0.3$ (literature on scientific analysis refers 0.3 to a medium statistical correlation [16]), were identified and a significance test ($\alpha = 0.01$) was set. This procedure provides the universally validity of key performance indicators for research alliances like the CoE-"TMFB" [17]. Successfully identified KPIs are for example frequency, quality and benefits of meetings; scientific cooperation and publications [9] The summary of the two statistical analyzes are visualized in Fig. 4.

In the first funding period, it hast been demonstrated that the BSC is able to steer and regulate the CoE on a high aggregation level (i. e. cluster management) [9]. The access to evaluation data and thus to recommendations of action is possible only in large time intervals, which poses a limiting factor to the way of proceeding. To improve interdisciplinary cooperation and to make cluster performance transparent, research approaches on micro-level will be adjusted appropriately. Performance measurement will be complemented by management attempts with the objective of fostering interdisciplinary cooperation and enhancing the quality of research processes and output.

## 4 Challenges of Performance Measurement

Own research, insights of the cluster management and current studies on management and measurement approaches in public funded organizations expose and refer to unused potential of collaborative cooperation [8, 18, 19]. Using this capability aims to support effectiveness inter alia in the public sector [17]. Public funding organizations like the German Research Foundation or the German Council of Science and Humanities express the need for developing further concepts to measure, steer and regulate scientific collaborations [17, 20]. Over the last decade – but especially after the first funding period of the CoE in Germany- there has been a continuous call for (advanced) performance management research like performance management systems (PMS) to use its potential efficiently [20].

The increased demand of designing, adopting and implementing performance management systems (PMS) in non-profit organizations is discussed in various papers [8, 19]. The growing demand of performance management systems can be explained by identifying the potential of performance management in contrast to performance measurement, but how is PMS defined? While performance measurement is the process of assessing progress towards achieving predetermined goals, performance management is building on that process, adding relevant communication and action achievements against these predetermined goals [19].

Capturing the PMS grasp leads to an advanced performance measurement approach for the CoE-"TMFB" – explored within the second funding period. As a consequence for "TMFB" – further development with regard to advanced performance measurement is needed and reflects the actual research efforts, with the objective of fostering interdisciplinary cooperation and transparency.

## 5 Advanced Performance Measurement in the Cluster of Excellence "Tailor-Made Fuels from Biomass"

To deal with demands of the DFG and German Council of Science and Humanities to make the CoE performance transparent and assessable, a PMS shall be adapted in the CoE and supplemented to the proven BSC. Within the scope of the second funding period, research on the following areas will be promoted.

*Recursion Layers* While the BSC measures the cluster performances on an aggregate cluster level, interdisciplinary cooperation and performance on a micro-level (e. g. project- and subproject-level) must be explored. Here to for instance an adequate, user-oriented (discipline specific) system architecture must be developed and implemented. To achieve interdisciplinarity on the whole cluster level, cooperative collaboration on lower cluster levels must be coexisting. A detailed view on the micro-level provides the opportunity to measure, steer and regulate particularized and individually on different recursion levels to foster discipline specific interdisciplinary collaboration and thus increase the performance of the whole cluster.

*Key Performance Indicators* In order to deal with performance on micro-level, it is necessary to operationalize specific performance indicators, which are able to measure specific scientific performance. Therefore it is necessary to analyze and operationalize the requirements i. e. of the cluster management, projects and subprojects (researcher), industrial partners or the research funding organizations. More thematic key aspects such as output, interdisciplinary, international presence, impact of the cluster as a system and internal process enhancement have to be considered. After operationalizing and evaluating the new performance indicators will be evaluated and validated as shown in Fig. 4 (performance measurement analysis).

*Time Series* Whereas the BSC is placed once a year, the advanced performance measurement approach will be implemented process-accompanying. Thus, the acquisition period of data (e. g. by the aid of an electronically questionnaire) will be increased additionally. Continual data collection and analysis are intended with the objective of increasing the reaction time for the SCA and simultaneously for the cluster management.

*Automatic Acquisition* Up to now the data acquisition is to a great extend manual work. The same procedure takes effect while analyzing data and deriving measures. Objective of the advanced performance measurement system is the self-controlled, systematically and automatically analysis of scientific output produced by the (sub-)projects of the CoE.

*Quality of Processes/Quality Management* While measuring the degree of target achievement is supposed to be more relevant in DFG-audits, the quality of internal, interdisciplinary processes is an important indicator of cluster-internal target achievement, too [14]. By the general idea of funding CoEs, one objective is the improvement of the quality of research output [15]. Therefore one CoE-suitable of the existing quality management systems [21] will be derived to manage the cluster process quality to the highly knowledge-intensive research association's needs. The improvement of the quality of processes will be supported by the investigation of potential for optimization and efficient cross-linking of the CoE members. This aspires a more efficient use of resources parallel to a continuously high quality of research results.

*Agile Management* The main objective and long-term goal of the CoE-"TMFB" is to determine the optimal combination of fuel components and their production processes, which is based on renewable raw materials and new combustion processes [6]. Referring to agile project management methods and transferring iterative-incremental software-development processes onto the structure and needs of the CoE, the PMS will be justified to the principles (shown in Table 1) of the agile manifest [22].

**Table 1** Principles of agile manifest

| | |
|---|---|
| I | Individuals and interactions take priority of processes and tools |
| II | Functional products take priority of vast documentation |
| III | Collaboration with customers takes priority of contract negotiations |
| IV | Going into modifications takes priority of rigorous plan-pursuance |

Advantages of agile management methods are for instance increasing the ability to react onto varied circumstances and adapt varying needs of employees or management, launching appropriate actions, steadily quality management and increasing motivation of all employees [23].

*Recommendation of Action* The different actors within the CoE require research/performance-information for various reasons and thus demands and expectations diverge [3]. Not only the cluster management obtains appreciable recommendations of action, but rather all cluster-actors get individual access to target group adaptive rehashed recommendations.

Taking these aspects into consideration and transferring them into a BSC supplementing approach will be part of research within the second funding period of "TMFB". Thereby operationalizing impartial, discipline specific (e. g. biology, chemistry, engineering) indicators is as challenging as operationalizing indicators in general to measure the performance in the CoE [24]. Groundwork while operationalizing specific indicators will be the excellence criteria defined by the DFG, i. e. quality of research, originality and coherence of scientific program, interdisciplinary collaboration, influences on future research areas, transferability, excellence and further development of researchers, equal opportunities etc. [14]. Especially creating objective indicators is hard to please [1]. Probably econometrically appraisal procedures in this context have to been proven. Hereby focus lies on efficiency-measurement rather than on productivity-measurement. Thus multiple input/output relationships can be depicted and information onto theoretical production function can be considered. In the end a methodical and econometrically established representation of performance can be possible [25].

## 6 Summary and Vision

During the first funding period, performance measurement is successfully implemented by the adaption of the BSC. Therefore suitable performance indicators are identified and evaluated. Research funding organizations demand further performance measurement, so that a PMS for the CoE-"TMFB" will be explored.

Within the frame of the second funding period a performance management system will be developed to supplement the BSC in the CoE. By exploring a new approach it might be possible to operate at all levels of research work and square target-

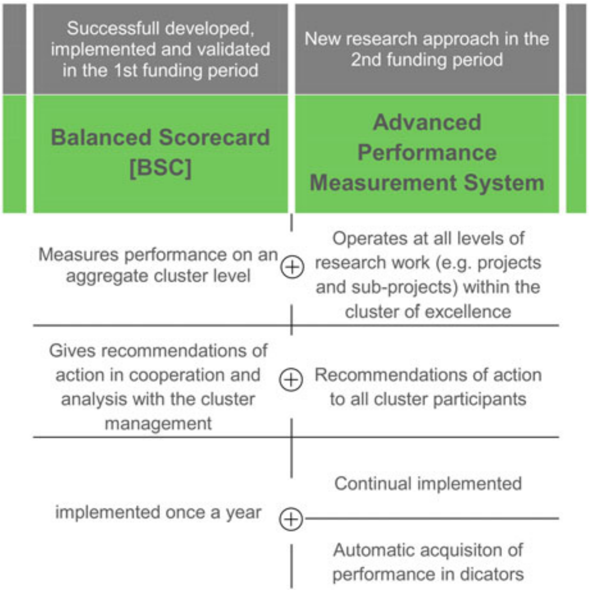


**Fig. 5** Development and features of the advanced performance measurement approach

performance within the CoE (micro-level). By this, recommendations of action shall be given to all levels of actors/researchers automatically and at any time. Furthermore, continual measuring and managing the performance of the CoE is supposed to be covered. Differences to the already elaborated BSC are shown in Fig. 4.

Continuous measuring and managing the degree of interdisciplinary cooperation, target achievement and as a whole the performance of the CoE is supposed to be covered by the depicted research approach. Reason is for instance increasing efficiency of research work, but even so accomplishing a basis for DFG audits. This aspires a more efficient use of resources parallel to a continuously high quality of research results. The vision of SCA is to lead the CoE into sustainability by supporting the cluster management (Fig. 5).

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# Measuring Regional Innovative Capability – Development of an Extended Set of Indicators

**Sebastian Stiehm, Florian Welter, René Vossen and Sabina Jeschke**

**Abstract** Regional innovative capability is described through a complex interaction of the dimensions human, organization and technology, which needs to be measured in a differentiated manner. The objective of this paper is the development and testing of an extended set of indicators as the basis of a measuring instrument for regional innovative capability. Therefore, three existing approaches provide the basis for the compilation of this extended set. Influenced by fundamental and formal requirements, key indicators as well as certain add-on indicators are identified, which are verified on the example of the Aachen region in Germany (This paper represents the working process and the results of an unpublished master's thesis by the first author. The full validation of the extended set of indicators on the example of the Aachen region can be provided by the author). The Aachen region shows many distinct characteristics of indicators allowing a reflection of regional innovative capability. This developed set of indicators represents the basis for a further development towards a measurement and management tool that enables the more precise evaluation of the innovation capability of a region, as well as statements on sensitive control factors of regional development.

**Keywords** Regional Innovative Capability · Hexagon Model · Operationalization · Indicators · Measurement · Regional Development

## 1 Introduction and Problem Statement

In today's complex and dynamic world economy the ability of a country or a region to innovate continuously is crucial for its competitiveness. Also at the regional level, innovative capability has recently been identified as a crucial determinant of social stability and economic growth [1]. Targeting the development and modelling of innovative capability, suitable measuring instruments at the regional level are

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required. Previous spatial scientific measurement approaches do not adequately consider that innovative capability substantially diverges at the regional level due to certain location factors.

To foster a country's sustainable competitiveness, regional innovation potentials have to be detected at an early stage and they have to be systematically exploited to finally increase the innovative capability [2]. Existing approaches and models are built primarily to measure the innovative capability of enterprises, networks or countries (e. g. *European Commission - Innovation Union Scoreboard, Deutsche Telekom Stiftung & Bundesverband der deutschen Industrie e. V. – Innovationsindikator*). Especially with regard to a smaller scale of measuring regional innovative capability, fewer approaches are available and applicable (e. g. *European Commission - Regional Innovation Scoreboard*). The aim of this paper is to develop a wider, regional small-scale, spatially differentiated and precise set of indicators for measuring and modelling regional innovative capability.

## 2 Operationalizing Regional Innovative Capability

Innovations are an important factor of economic growth and regional development [3]. In the early twentieth century Schumpeter already emphasized the importance of innovation as the driving force of economic development and structural change [4]. The challenge is that innovations are fraught with uncertainty and risk, and so the failure rate of technical innovation projects is 50 % [5]. Therefore, it is of great interest to identify innovative capabilities and the critical factors for innovation success more accurately [6]. For defining the term regional innovative capability, it is broken down into single components. Innovative capability is being defined, before spatial and regional aspects are involved.

Contemporary research mainly focuses on success factors, characteristics and criteria of successful innovations. However, innovative capability is rarely a subject of theoretical and empirically grounded research literature [6]. Basically, it means the ability of individuals, groups, institutions or networks to continuously innovate [7]. A system-oriented approach towards innovative capability is crucial: Cantner [8] points out the importance of interaction and collaboration of the elements of a system, which is based on the exchange of knowledge and experience. System's elements e. g. can be stakeholders like individuals or small and medium-sized enterprises (SME). Trantow et al. [7] have a similar system-oriented understanding of innovative capability: the ability to bring forth innovation requires a complex interaction of the dimensions human, organization and technology. Here, every innovation is always a result of the far-reaching inter-relations of these dimensions and interdependent processes that arise from it [7].

In the Oslo Manual (2005) the complex understanding of innovative capability is extended to a spatial and regional perspective [9]. Here, region-specific location factors crucially influence the creation of innovations. Accordingly, regional disparities are precisely examined and main characteristics identified in order to gain a better understanding of innovation processes: "*The notion that regional factors can influence the innovative capacity of firms has led to increasing interest in analyzing innovation at the regional level. Regional differences in levels of innovation activity can be substantial, and identifying the main characteristics and factors that promote innovation activity and the development of specific sectors at regional level can help in understanding innovation processes and be valuable for the elaboration of policy*" [9].

The challenge is to operationalize regional innovative capability. Basically, innovative capability is being operationalized analogous to innovations with input and output or process factors [10]. However, the significance of quantitative output-oriented indicators (e. g. patents) or input-based indicators (e. g. Research & Development (R&D) expenditure and employees) is not sufficient. In order to accomplish a more precise operationalization, the spatial- and the content-related dimensions of the complex system of regional innovative capability are defined in more detail during the following sections.

## *2.1 Spatial Dimension: Spatial Planning Region*

Innovative capability as well as innovation and development processes are influenced by the respective region. But what distinguishes a region more closely and which scale is reasonable for the proposed set of indicators for measuring regional innovative capability? In economic geography the terminus *region* is defined very broadly, it is considered as a contiguous space section [11].

The German Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) defines spaces on the one hand by administrative, on the other hand by functional criteria [1]. Here, counties[1] as authorities and holders of public tasks (especially in the function of lower state administrative bodies) constitute the administrative basis for the functional and spatial delineation of Spatial Planning Regions (SPRs). Therefore, SPRs are agglomerations of counties into functional units, which are characterized by commuters' relations towards a major regional centre [12].

In the German Federal Spatial Planning SPRs are applied to analyze large-scale disparities and developments and therefore they are of great interest for this work. On the one hand this spatial delineation is used if the county level is too fragmented, too spatially small or if the (federal) state level is too coarse. On the other hand SPRs are used to analyze and highlight intertwining relationships between major regional centers and surrounding areas [12]. The advantage of SPRs is that these are defined functionally and not purely in an administrative way, but at the same time statistically detectable, since they are based on the agglomerations of counties.

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1 European equivalent: NUTS-3 Regions. To harmonize the regional statistical reporting, the European Union has introduced a common classification of territorial units for statistics in the 1970 s (Nomenclature of Territorial Units for Statistics, NUTS) [12].

For example, besides commuting, also interactions and innovation links between peripheral enterprises and a university as a gravity core can be measured [12].

## 2.2 Content-related Dimension: Knowledge Region

Models of innovation-oriented regional development are used to operationalize the content-related dimension of regional innovative capability. These models are primarily used to establish an ideal state of the development objectives that have to be regionally pursued [13]. In the context of this study, concepts of regional development are considered to examine regions concerning their potentials and capabilities in terms of generating innovation. Finally, using these concepts, regional innovative capability can be operationalized.

Models of innovation-oriented regional development capture different conceptual facets of knowledge-based regional development [14]. By comparing five different models namely clusters, innovative or creative milieus, regional innovation systems, learning regions and knowledge regions (KR) [15–18], the KR turns out as a suitable model of regional development to finally develop a set of indicators for measuring regional innovative capability. The innovation-oriented regional development model of the KR by Fromhold-Eisebith [13] represents an overarching, linking framework of the compared, all previously pre-established regional development models. This model provides more of a regional development tool, which pursues strategic intentions, as a descriptive or analytical tool [13, 19]. The term KR emphasizes the importance of knowledge for the economic and social future of a region [20]. Furthermore, the operationalization of knowledge as the basis of innovation, offers an adequate approach towards the identification of regional innovative capability.

Fromhold-Eisebith [13] uses the clarification of knowledge in order to illustrate the advantages of the terminus KR over other regional development models. Due to the broad and socially accepted knowledge concept (e. g. explicit and tacit knowledge [21]), which refers to various areas of expertise, such as science, economy and society, the model of the KR activates and involves a wider range of stakeholders and competence-fields accordingly. This in turn promotes a greater information-sharing, more interactions and collaborations for knowledge generation and finally an increase of regional innovative capability. The concept of the KR with its large bandwidth for example also captures peripheral, rural areas [13]. To summarize, (regional) knowledge has a direct impact on the development process of a region and serve as a key factor for identifying specific regional capabilities which also determines the long-term position in the region.

The KR is characterized by flexible network-structures and a high degree of cross-linking. This implies a high grade of interaction and cooperation between internal and external stakeholders. Due to spatial proximity, social-cultural relations also play an important role. To understand these structures, the hexagon model portrays basic structure of the KR concept (cf. Fig. 1).

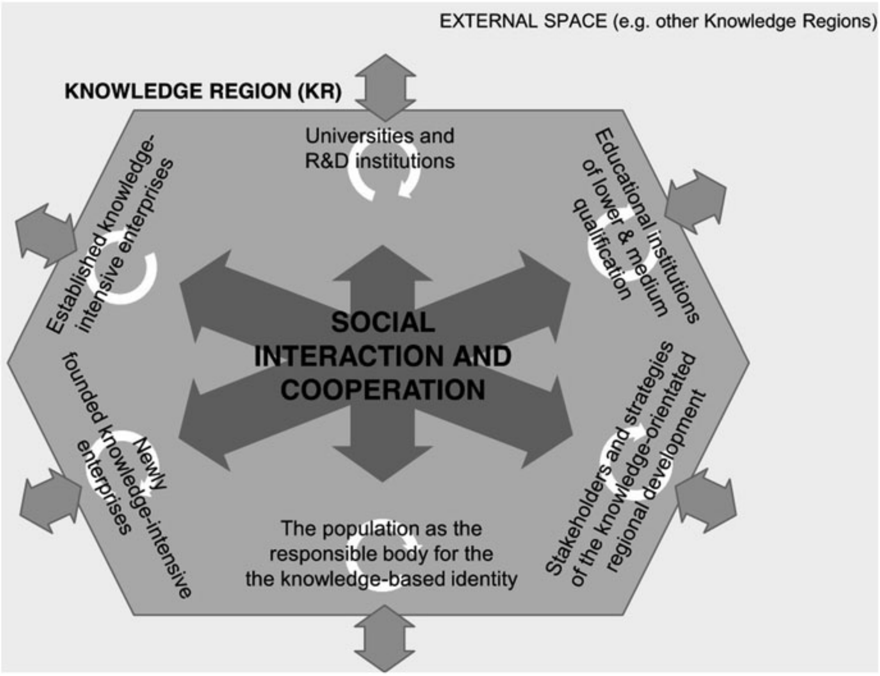


**Fig. 1** The hexagon model of the KR. (Source: own representation based on Fromhold-Eisebith [13])

This model outlines the demand for a modern knowledge-based regional development in form of an ideal image on the one hand, and strategy-based, regionally appropriate statements on the other hand [13]. Hence, the hexagon model represents stakeholders of knowledge-related processes. A KR can be exemplary captured by R&D intensity, by the number of R&D institutions or R&D employees, but also by the existence funding strategies or the knowledge-related self-image of the population [22].

To conclude, the concept of KR is suitable for the identification of the innovative capability of regions. Demands of a modern knowledge-based regional development in the means of social interaction and cooperation as well as strategy statements relating to the development of a region are pointed out in this concept. Furthermore, it provides content-related requirements for the development of an extended set of indicators to measure regional innovative capability.

**Table 1** Comparison of three different existing approaches measuring (regional) innovative capability. (Source: own representation)

| | BAKBASEL Innovations-Benchmarking | Regional Innovation Scoreboard | Innovationsindikator |
|---|---|---|---|
| N° OF INDICATORS | 7 | 12 | 38 |
| INTERNATIONAL FRAMEWORK | - | 24 countries | 28 countries |
| SPATIAL DIMENSION | NUTS 1, Planningregions | NUTS 2 | State |
| CONTENT RELATED DIMENSION | Regional Innovationsystems | - | National Innovationsystems |

**Table 2** Set of indicators - *Regional Innovation Scoreboard*. (Source: European Commission [23])

| Indicator | Dimension |
|---|---|
| Population with tertiary education per 100 population aged 25-64 | Enablers |
| Public R&D expenditures (% of GDP) | Enablers |
| Business R&D expenditures (% of GDP) | Firm Activities |
| Non-R&D innovation expenditures (% of total turnover) | Firm Activities |
| SMEs innovating in-house (% of all SMEs) | Firm Activities |
| Innovative SMEs collaborating with others (% of all SMEs) | Firm Activities |
| Public-private co-publications | Firm Activities |
| EPO patent applications per billion GDP (in PPP€) | Firm Activities |
| Technological (product or process) innovators (% of all SMEs) | Outputs |
| Non-technological (marketing or organisational) innovators (% of all SMEs) | Outputs |
| Employment in knowledge-intensive services / medium-high and high-tech manufacturing | Outputs |
| Sales of new-to-market and new-to-firm products (% of total turnover) | Outputs |

## 2.3 State of the Art: Sets of Indicators for Measuring Innovative Capability

To initiate the development of an expanded set of indicators three existing approaches are used in a literature study (cf. Table 1). The consideration focuses on the quantification and qualification of the contained sets of indicators. It examines how innovation capability is operationalized at different spatial dimensions. Further actions such as index calculations or other additional procedures are not considered. The selection of these three approaches founded on one certain criterion: The measurement of innovative capability of countries or regions, and not the measurement of the innovative capability of enterprises.

The *Regional Innovation Scoreboard* by the European Commisson refers on the comparability of the NUTS-2 regions of 24 European countries [23]. Such an extensive comparative study requires corresponding data sources, which have to be accompanied by statistical estimates. The challenge here is the nationwide regional data availability. Innovative capability is described by 12 indicators, which refer to three dimensions. "Enablers" capture the main drivers of innovation performance external to the firm, "firm activities" refer to the innovation efforts at the level of the firm and "outputs" imply further effects of firm-based innovation activities [cf. Table 2] [23]. Concerning the content related dimension, no more specifications in the meaning of models of regional development are made.

**Table 3** Set of indicators - *Innovationsindikator*. (Source: DTS/BDI [24])

| Indicator | Dimension |
|---|---|
| Foreign students as a percentage of all tertiary enrolment | Education |
| Share of employees with at least secondary (non tertiary) education | Education |
| Population with ISCED 6 level education in mathematics, sciences, and engineering | Education |
| Tertiary graduates per 55+ year old academic employees | Education |
| Share of employees with tertiary education | Education |
| Annual education expenses per student | Education/State |
| Quality of education system | Education/State |
| Quality of the mathematical and natural science education | Education/State |
| Index of PISA results in sciences, reading, mathematics | Education/State |
| E-readiness indicator | Society |
| Risk-taking behavior | Society |
| Number of PCs per 100 inhabitants | Society |
| Share of post materialists | Society |
| Public demand for advanced technologies | State |
| Demand of companies for technological products | Enterprises |
| Early-stage venture capital relative to GDP | Enterprises |
| Importance of Marketing | Enterprises |
| Share of international co-patents | Enterprises |
| Share of value added in high-tech sectors in total value added | Enterprises |
| Share of employees in knowledge intensive services | Enterprises |
| Intensity of competition | Enterprises |
| GDP per capita | Enterprises |
| Transnational patents per capita | Enterprises |
| USPTO patent applications per capita | Enterprises |
| Value added per hour worked | Enterprises |
| Trade balance in high-tech goods per capita | Enterprises |
| Share of university R&D financed by enterprises | Enterprises |
| Internal business R&D expenditures as share of GDP | Enterprises |
| B-index for tax-based funding of business R&D | Enterprises/State |
| Publicly funded R&D in enterprises as a share of GDP | Enterprises/State |
| Number of researchers in FTE per 1,000 employees | Public Research |
| Number of SCI publications relative to population | Public Research |
| Quality of research institutions | Public Research |
| Field-specific expected impact rate of SCI-publications | Public Research |
| Public science sector patents per inhabitant | Public Research |
| Share of international SCI co-publications | Public Research |
| R&D share in Public Research Institutions and Universities | Public Research |
| Country share among the top 10% of most highly cited publications | Public Research |

The *Innovationsindikator* reflects the most detailed portray of innovative capability [24]. With using 38 indicators different dimensions like education, society, enterprises and public research are operationalized. In comparison to the other approaches the understanding of innovative capability is wider and includes more certain aspects, like the quality of the education system or the Index of PISA (cf. Table 3). Nevertheless, the focus is on the dimension enterprises, which is described by almost 15 indicators. Some qualitative indicators of this approach are based on expert interviews, which significantly imply more effort for the survey, since no pure query of available data is possible. The content-related dimension of the *Innovationsindikator* is described by national innovation systems as a model of regional

**Table 4** Set of indicators - *BAKBASEL Innovations-Benchmarking*. (Source: BAKBASEL [25])

| Indicator | Dimension |
|---|---|
| R&D expenditures | INPUT |
| R&D intensity | INPUT |
| Papers in scientific publications | INPUT |
| Shanghai-Index | INPUT |
| Students | INPUT |
| Patens | OUTPUT |
| Size of the knowledge-intensive business sector | OUTPUT |

development (cf. Table 1). Considering the international framework, the *Innovationsindikator* refers to the comparison of 28 industrialized countries. Any further regional specifications are not made.

The approach of *BAKBASEL Innovations-Benchmarking* covers different phases and aspects of an innovation process using 7 indicators [25]. These are divided into the input and output dimension of an innovation process. In comparison to the other two approaches, the description and identification of innovative capability relies on a few core indicators, such as patents, R&D expenditures or papers in scientific publications (cf. Table 4). Considering the spatial framework, the *BAKBASEL Innovations-Benchmarking* only focuses on the German federal state of Baden-Württemberg as well as on smaller-scale planning regions, thereby the view is much more limited and focused. The content-related dimension of the *BAKBASEL Innovations-Benchmarking* is described respectively by models of regional development – in this case regional innovation systems (cf. Table 1). A special feature is the combination of a spatially and functionally defined region (Planningregions) on the hand and an innovation-orientated model of regional development on the other hand. This combination approaches the intended procedures of this work already quite closely.

Reflecting Table 1 it becomes obvious that innovation is described by manifold indicators and in very different degrees. Based on this cross-sectional choice of different approaches, it has been highlighted, which sets of indicators are used to measure innovative capability and what selection of indicators is necessary for determining the innovative capability of SPRs regarding the development of the proposed set of indicators.

## 3 Development of an Extended Set of Indicators

An extended approach is derived from the previously highlighted indicators of the three sets of indicators described. This derivation happens in a compaction process under influence of formal requirements based on the Grounded Theory Methodology[2]. Thus, a compressed data corpus is generated through encoding. The encoding

[2] Grounded theory describes a curriculum related theory-formation, which has been described by the sociologists GLASER and STRAUSS 1967 in the book "The Discovery of Grounded Theory" first time fundamentally [26].

**Table 5** Fundamental and formal requirements. (Source: own representation)

| Fundamental requirements | Formal requirements | | |
| --- | --- | --- | --- |
| Universities and R&D institutions | (Regional) Data availability | Clear assesment | Operating efficiency |
| Established knowledge-intensive enterprises | | | |
| Newly founded knowledge-intensive enterprises | | | |
| The population as the responsible body for the knowledge-based identity | | | |
| Stakeholders and strategies of the knowledge-oriented regional development | | | |
| Educational institutions of lower & medium qualification | | | |

process represents the core of Grounded Theory. In order to enable a systemic analysis, collected data is abstracted, categorized and put into an interdependent context. During the open coding, categories are identified and described hypothetical. Existing data is coded accordingly towards its conceptual content. The resulting codes can be construed as preliminary concept names. The previously developed concepts are then further refined during axial coding. Thus, the differentiation rotates at a certain point around the axis of a concept or a category. During the axial coding, categories are related to each other and further sub-categories are analyzed. Finally, key categories (=indicators) are identified [26].

## *3.1 Requirements*

The fundamental requirements for the proposed set of indicators are given by the six edges of the hexagon model (cf. Fig. 1), which represent the stakeholders of knowledge-based processes. These stakeholders are required in sufficient availability and quality for the creation, the use and the transfer of knowledge in order to strengthen innovative capability (cf. Table 5).

In addition to these fundamental requirements for the justification of the proposed set of indicators, more formal requirements are needed, such as (regional) data availability, clear assessment and operating efficiency. Clear assessment implies the definition of explicit parameters or key figures and operating efficiency involves a proportionally cost/benefit ratio concerning the data collection. For the identification of the extended set of indicators all formal requirements have to be equally respected. However, the availability and quality of data at the regional planning level is decisive.

## *3.2 Identification of Key Indicators*

In comparison of the three sets of indicators, a data corpus of 57 codes emerged through open coding which generally describes regional innovative capability[3].

[3] Full tables can be provided by the author.

**Table 6** Overview of the extended set of indicators. (Source: own representation)

<table>
<tr><th>Input</th><th>Output</th></tr>
<tr><td>GDP</td><td rowspan="4">Patents</td></tr>
<tr><td>R&D expenditures of the business sector</td></tr>
<tr><td>R&D employees in the business sector</td></tr>
<tr><td>Publications</td></tr>
<tr><td>Ten percent of the most cited scientific and technical publications</td><td rowspan="3">Size of the knowledge-intensive & medium- / high-tech-business sector</td></tr>
<tr><td>Excellent Research</td></tr>
<tr><td>Foreign Students</td></tr>
<tr><td>Students</td><td rowspan="4">International interrelations of the knowledge-intensive & medium- / high-tech-business sector</td></tr>
<tr><td>Population with tertiary education</td></tr>
<tr><td>Public R&D expenditures *</td></tr>
<tr><td>Venture-Capital*</td></tr>
<tr><td>Knowledge-regional initiatives**</td><td>Enterprises innovating in-house **</td></tr>
<tr><td>Technology and business incubator-centres**</td><td rowspan="2">Home institutions of enterprises of the knowledge-intensive business & medium- / high-tech-business sector **</td></tr>
<tr><td>Regional cluster and network initiatives**</td></tr>
<tr><td colspan="2">* Add-on-A-Indicator, ** Add-on-B-Indicator</td></tr>
</table>

Through axial coding, the previously open encoded codes were again compressed to twelve codes and through selective coding into two categories (cf. Table 6). After this, the extended set of indicators has been compacted and derived in accordance with the given requirements. This allowed a justification and validation in accordance with the requirements of the KR.

### 3.3 *Identification of Additional Indicators*

In accordance with the introduced fundamental and formal requirements, key indicators were identified and additional indicators could be developed. Here, a distinction is made between Add-on-A-Indicators and Add-on-B-indicators (cf. Tables 6 and 7): Add-on-A-indicators have also been raised from the above-described compression step from the existing indicator sets. However these do not meet the formal requirements i. e. that they are either difficult or impossible to collect. This is why these indicators cannot be counted among the key indicators. Nevertheless, the Add-on-A-indicators meet the fundamental requirements. Despite the non-fulfillment of formal requirements they contribute to the validity of the set of indicators regarding the portraiture of regional innovative capability.

Definitions of the Add-on-A-indicators can be found, as well as those of the key indicators, in the different considered indicator sets. Add-on-B-indicators are indicators that cannot be found in the considered indicators sets, however, they are additionally required to describe regional innovative capability and KRs. Accordingly, Add-on B-indicators fulfill fundamental and formal requirements, but due to their new construction they also cannot be counted among the key indicators. Table 6

**Table 7** Specification of the extended set of indicators. (Source: own representation)

| | Fundamental requirements | Formal requirements | Derived | Newly developed |
|---|---|---|---|---|
| Key indicators (12) | ☑ | ☑ | ☑ | |
| Add-On-A-Indicators (3) | ☑ | | ☑ | |
| Add-On-B-Indicators (4) | ☑ | ☑ | | ☑ |

shows the complete and extended set of indicators in a summarizing, conceptional overview. In the entire academic work all indicators are fully defined, justified and explicitly described by parameters or key figures.

## 4 Evaluation and Application-oriented Outlook

The extended set of indicators has been tested for its functionality in the context of the Aachen region. Observations are that e. g. scientific clusters of excellence contribute to increase the innovative capability in the region of Aachen or that a high density of technology-, start-up- and service-centers promote innovation. Furthermore, the Aachen region is strong in the area of knowledge-intensive as well as medium- and high-tech enterprises without being characterized by a strong urban-rural gradient. In addition, the region is characterized by a functioning transfer between scientists and citizens [27].

Overall the Aachen region shows many distinctive characteristics of indicators that suggest being an innovative capable region. Regional innovative capability can therefore be portrayed with the developed broader approach, although more precise statements about the innovative capability of a region are not possible here: The interpretability of these collected data is restricted due to missing observation spaces, data series and a further consideration of comparable regions.

## 5 Summary and Outlook

The example of the Aachen Region shows that the extended set of indicators is able to reflect regional innovative capability. As a spatial dimension, SPRs serve to capture regional innovative capability, which are suitable for large-scale analyzes, regional forecasting as well as large regional surveys to detect interactions and innovation links. In addition, the model of KR delineates the content-related dimension of the proposed set of indicators, not at least because this model links many existing models of regional development.

An option is the development of this extended set of indicators towards a full measurement and control tool of knowledge-regional development by considering these missing aspects and by weighting the individual indicators. So, for example, even sensitive control variables can be identified. Finally, an index value of all indicators can also be formed in such a way whereby a direct comparison of different regions is allowed. A comparable index is e. g. shown by the *Regional Innovation Scoreboard* or by the *Innovationsindex*. Another further step is the ongoing evaluation of this set of indicators on other regions in the meaning of long-term studies. The development of this set of indicators towards a measurement and management tool will allow more accurate statements about the innovative capability of a region.

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# Operationalizing Regional Innovative Capability

**Sebastian Stiehm, Florian Welter, René Vossen and Sabina Jeschke**

**Abstract** The capability of regions to continuously innovate constitutes a key factor for competitiveness. Regional innovative capability is described through a complex interaction of the dimensions human, organization and technology, which needs to be measured in a differentiated manner. This paper aims at the identification and operationalization of regional innovative capability. The objective is to compile an extended set of indicators to provide a basis for a further development towards a measurement and management tool that enables the more precise evaluation of the innovation capability of a region, as well as statements on sensitive control factors of regional development.

**Keywords** Regional Innovative Capability · Knowledge Region · Hexagon Model · Operationalization · Indicators · Measurement · Regional Development · Models of Innovation-Oriented Regional Development

## 1 Introduction and Problem Statement

At the regional level, innovative capability has recently been identified as a crucial determinant of social stability and economic growth [1]. Targeting the modelling of innovative capability, suitable measuring instruments at the regional level are required. The majority of measurement approaches in spatial science do not adequately consider that innovative capability substantially diverges at the regional level due to certain location factors [2].

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## 2 The Hexagon Model of the Knowledge Region as an Approach to Regional Innovative Capability

Innovative capability comprises the complex interrelationships between the human, organizational and technological requirements to continuously create and realize new ideas, which contribute to sustainable changes [3]. In the Oslo Manual [4] the understanding of innovative capability is extended to a spatial and regional perspective: Region-specific location factors crucially influence the creation of innovations and regional disparities have to be precisely examined [4, 5]. This leads to the challenge to operationalize regional innovative capability. However, the significance of quantitative output-oriented indicators (e. g. patents) or input-based indicators (e. g. Research & Development (R&D) expenditure and employees) is not sufficient. In order to accomplish a more precise operationalization, the content-related dimensions of the complex system of regional innovative capability have to be defined: To operationalize the content-related dimension of regional innovative capability, models of innovation-oriented regional development are applied.

In this paper, concepts of regional development are considered to examine regions concerning their potentials and capabilities in terms of generating innovation. The innovation-oriented regional development model of the Knowledge Region (KR) by Fromhold-Eisebith [6] represents an overarching, linking framework of pre-established regional development models (e. g. clusters, innovative or creative milieus, regional innovation systems, learning regions). Thus, in this paper the model is used as a base to develop a set of indicators for measuring regional innovative capability.

The KR is characterized by flexible network-structures and a high degree of cross-linking. This implies a high grade of interaction and cooperation between internal and external stakeholders. Due to spatial proximity, social-cultural relations also play an important role. To understand these structures, the hexagon model portrays the basic structure of the KR concept (cf. Fig. 1).

## 3 Developing an Extended Set of Indicators by Using the Hexagon Model

To initiate the development of an expanded set of indicators, three existing approaches are used in a literature study (c.f. Table 1). The consideration focuses on the quantification and qualification of the contained sets of indicators. It examines how innovative capability is operationalized at different spatial dimensions.

### *3.1 Requirements*

The fundamental requirements for the proposed set of indicators are given by the six edges of the hexagon model (c.f. Fig. 1), which represent the stakeholders

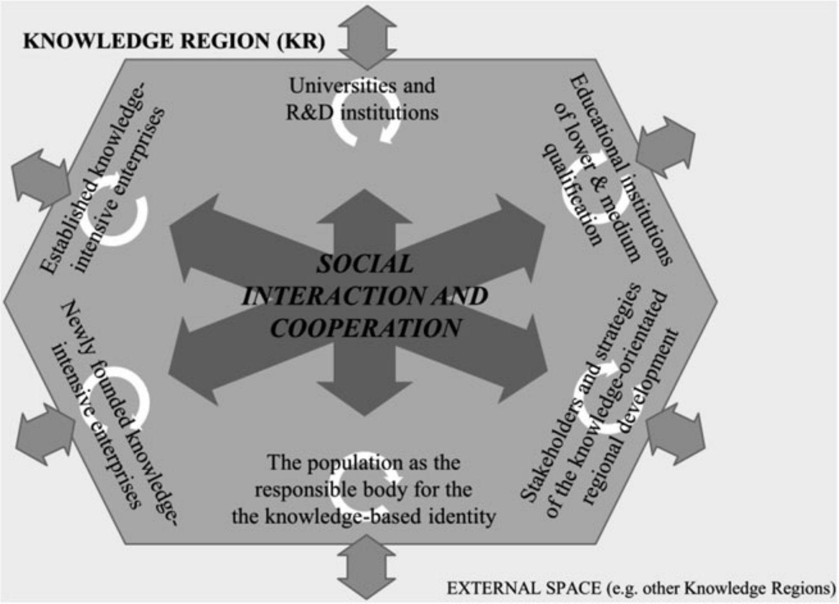


**Fig. 1** The hexagon model of the KR. (Source: own representation based on Fromhold-Eisebith, 2009)

**Table 1** Comparison of three different existing approaches measuring (regional) innovative capability. (Source: own representation based on BAKBASEL [7]; European Commission [8]; DTS and BDI [9])

| | *BAKBASEL Innovations-Benchmarking* | *Regional Innovation Scoreboard* | *Innovationsindikator* |
|---|---|---|---|
| *N° OF INDICATORS* | 7 | 12 | 38 |
| *INTERNATIONAL FRAMEWORK* | - | 24 countries | 28 countries |
| *SPATIAL DIMENSION* | NUTS 1, Planningregions | NUTS 2 | State |
| *CONTENT RELATED DIMENSION* | Regional Innovationsystems | - | National Innovationsystems |

of knowledge-based processes [10]. These stakeholders are required in sufficient availability and quality for the creation, use and transfer of knowledge in order to strengthen innovative capability (c.f. Table 2).

In addition to these fundamental requirements for the justification of the proposed set of indicators, more formal requirements are needed, such as (regional) data availability, clear assessment and operating efficiency. Clear assessment implies the definition of explicit parameters or key figures and operating efficiency involves a proportionally cost/benefit ratio concerning the data collection. For the identification of the extended set of indicators all formal requirements have to be equally considered. However, the availability and quality of data at the regional planning level is decisive.

**Table 2** Fundamental and formal requirements. (Source: own representation)

| *Fundamental requirements* | *Formal requirements* | | |
|---|---|---|---|
| | (Regional) Data availability | Clear assesment | Operating efficiency |
| Universities and R&D institutions | | | |
| Established knowledge-intensive enterprises | | | |
| Newly founded knowledge-intensive enterprises | | | |
| The population as the responsible body for the knowledge-based identity | | | |
| Stakeholders and strategies of the knowledge-oriented regional development | | | |
| Educational institutions of lower & medium qualification | | | |

## *3.2 Identification of Key Indicators*

The following indicators are derived from the approaches in Table 1. The derivation happens in a compaction process based on the Grounded Theory Methodology [11]. A compressed data corpus is generated through encoding of qualitative data that is given in the mentioned approaches. During the encoding process, categories are identified and then analyzed. So, in order to enable a systemic analysis, collected data is abstracted, categorized and put into an interdependent context [12]. Key categories (=indicators) match the fundamental and formal requirements. The information given in the quotation marks means the original source of derivation.

**Indicator – GDP:** The Gross Domestic Product per capita the leading economic indicator of economic strength and prosperity. The modern growth theory provides a clear and causal link between innovation and growth, as well as long-term capital formation of the economy. According to this theory, a greater investment in innovation activities influences the growth of prosperity positively. This indicator addresses all edges of the hexagon model (Innovationsindikator).

**Indicator – R&D Expenditures of the Business Sector:** This indicator covers all in-house R&D activities, regardless of the respective type of funding. This also contains R&D activities, which are carried out as research contracts from third parties. This indicator includes the creation of new knowledge in established and newly founded knowledge-intensive enterprises. The reference to the business sector on the one hand is based on data availability. On the other hand, apart from state and science, over 75 % of R&D expenditures are generated in this sector (Regional Innovation Scoreboard, Innovationsindikator).

**Indicator – R&D Employees in the Business Sector:** All persons are considered who directly take over tasks of R&D within an enterprise, as well as R&D-related services (e. g. management, administration). The number of R&D employees is a leading indicator for the input of the science system. R&D employees combine the potential and expertise of established or newly founded knowledge-intensive enterprises. The reference to the business sector has already been described in the previous indicator (Innovationsindikator).

**Indicator – Publications** Here, acknowledged scientific publications are considered. Scientific publications with regional authorship allow statements about the academic knowledge base of a region. This indicator functions for the estimation of innovation activities in the field of universities and R&D facilities as well as for the population as a carrier of knowledge-related identity (BAKBASEL, Regional Innovation Scoreboard, Innovationsindikator).

**Indicator – Top 10 % of the Most Cited Scientific and Technical Publications** The focus is on the percentage of publications of a university belonging to the top 10 % most cited publications. This indicator measures the ability of a region to produce publications, which are among the most frequently cited. This means that a special level of quality and impact is supposed for the publications. Therefore, in the field of universities and R&D facilities this indicator is a measure of the ability to produce elite or pioneering research (Innovationsindikator).

**Indicator – Excellent Research** This indicator shows whether the region includes R&D facilities that operate excellent research. Excellent research in form of clusters of excellence, graduate schools or future concepts provides information on the national and international visibility of the research location (universities and R&D facilities). The aim of the German Excellence Initiative i. e. is to promote innovative cutting-edge research at German universities and thus to make universities internationally visible and competitive [13]. In graduate schools young researchers are explicitly supported and in clusters of excellence scientific networking and interdisciplinary collaborations are strengthened. Future concepts thereby promote additional measures, which enable the universities to develop their international profile in order to promote to the top group of international excellent universities (Innovationsindikator).

**Indicator – Foreign Students** Here, the proportion of foreign students in the total number of students in the region is measured. On the one hand this indicator expresses the attractiveness of science for international students, on the other hand this indicator measures the willingness of a group of internationally mobile students of taking classes in a specific region or university. Considering the fundamental requirements of the KR Universities and R&D facilities as well as parts of the population are addressed as a carrier of knowledge-related identity in relation to interaction and cooperation (Innovationsindikator).

**Indicator – Students** This indicator measures the density of students per employees. The number of students is one of the most important indicators to evaluate the outputs of a university system. The number of students and their distribution among the various groups of subjects determine the short to medium term availability of regional human capital. Therefore, students are considered to be a key input factor for future innovation processes. In a KR students may be counted as a special part of the population, because they are carriers of knowledge-related identity (BAKBASEL).

**Indicator – Population with Tertiary Education** This indicator measures the proportion of employees with tertiary education (e. g. universities, technical schools).

This is a general indicator for the supply of highly qualified personnel. The development and introduction of innovation requires sufficient know-how and skills. Together with PhD students and PhD graduates, this represents one of the most important resources for a KR. Innovative capability is thus based on the population as a carrier of knowledge-related identity of the knowledge region (Regional Innovation Scoreboard, Innovationsindikator).

**Indicator – Patents** Here, published patents at the German Patent and Trademark Office are measured. The measurement of the amount of patents is a popular way of measuring innovative capability respectively output. With patents, economically exploitable research results (innovations) are protected and statistically recorded. Published and granted patents thus show the amount of economically useful information, which are the results of R&D processes. Especially actors such as universities and R&D facilities as well as established and newly founded knowledge-intensive firms are queried for their ability to innovate (BAKBASEL, Regional Innovation Scoreboard, Innovationsindikator).

**Indicator – Size of the Knowledge-Intensive & Medium-/High-Tech-Business Sector** This indicator provides information on the size of the knowledge-intensive and medium-high and high-tech segment of the economy. This is fixed by an Eurostat definition in accordance to the NACE classification [5]: manufacturing high-tech industry (NACE 21, 26), manufacturing medium-high-tech industry (NACE 20, 27–30) and knowledge-intensive services (NACE 50–51, 58–66, 69–75, 78, 80, 84–93). Primarily established or newly established enterprises in the knowledge-intensive economy are characterized by a higher average of innovation activity and a higher value-added growth. Economies with strong knowledge-intensive industries accordingly have a high capability for innovation. (Regional Innovation Scoreboard, BAKBASEL, Innovationsindikator).

**Indicator – International Interrelations of the Knowledge-Intensive & Medium-High-Tech-Business Sector** The Focus is the share of international enterprises on the total number of knowledge-intensive & medium-high-tech-enterprises in regions. 50.01 % as the threshold proportion of foreign shareholders are chosen for the delineation of enterprises using the NACE classification by Eurostat. In addition to the importance of knowledge-intensive economy for the innovation capacity of a region, international integration plays a substantial role. The innovative capability of KR is based not only on internal, but also external interaction and cooperation of knowledge-intensive enterprises (Regional Innovation Scoreboard, BAKBASEL, Innovationsindikator).

## *3.3 Identification of Add-On-Indicators*

After identifying key indicators, more indicators have to be identified to complete the set of indicators regarding its portraiture of regional innovative capability. However,

**Table 3** Specification of the extended set of indicators. (Source: own representation)

| | *Fundamental requirements* | *Formal requirements* | *Derived* | *Newly developed* |
|---|---|---|---|---|
| *Key indicators (12)* | ☑ | ☑ | ☑ | |
| *Add-On-A-Indicators (3)* | ☑ | | ☑ | |
| *Add-On-B-Indicators (4)* | ☑ | ☑ | | ☑ |

these indicators either do not fulfill the previously introduced formal requirements or they are not derived from the existing indicator sets, but newly developed. A distinction is made between Add-on-A-Indicators and Add-on-B-Indicators (c.f. Table 3): Add-on-A-Indicators have also been derived from the existing indicator sets, but they do not match the formal requirements due to missing regional data availability. Add-on-B-Indicators are newly developed based on the fundamental requirements of the KR. These cannot be found in the considered indicators sets, however, they strongly contribute to the validity of the extended set of indicators.

**Add-On-A-Indicator – Public R&D Expenditures:** This indicator provides information on the external or public R&D expenditure (federal, state or the EU). R&D expenditures are one of the main drivers of economic growth in a knowledge-based economy. Trends of this indicator provide important clues to the future competitiveness and prosperity of individual regions. Expenditure on research and development are essential to encourage the transition towards a knowledge economy and to improve the production technologies. Here, clearly stakeholders and strategies of knowledge-oriented regional development are adressed (Regional Innovation Scoreboard, Innovationsindikator).

**Add-On-A-Indicator – Venture-Capital:** The venture capital is measured in relation to the GDP. The commercialization of research results of start-up enterprises often requires significant investment in the early stages of technological development, including R&D, testing and marketing. This investment has to be executed before an enterprise is able to gain income from new products. Therefore, venture capital is an important source of financing. The amount of venture capital investments in early stage development of technology enterprises (i. e. seed and start-up phase) depicts an important indicator of the capability of a country, to support technology startups with sufficient financial resources. Here, clearly stakeholders and strategies of knowledge-oriented regional development as well as knowledge-orientated companies are addressed (Innovationsindikator).

**Add-On-A-Indicator – Enterprises Innovating In-house:** This indicator measures the degree of enterprises that have introduced new or significantly improved products or production processes on their own. This in-house innovation ability has a significant effect on the regional innovative capability. (Regional Innovation Scoreboard)

**Add-On-B-Indicator – Knowledge-Regional Initiatives:** Here, regional markets for knowledge-regional initiatives are measured. This indicator turns out if there are efforts in the region to involve the population in knowledge-regional initiatives in order to apply or to spread knowledge. Through the participation of the population into KR initiatives it becomes easier to convince the population by the benefits of a KR. The population is considered as an essential carrier of knowledge-related identity and the regional image, which in turn has an effect on the regional innovative capability.

**Add-On-B-Indicator – Technology and Business Incubator Centres** Technology and business incubators promote the creation of new knowledge-intensive enterprises in a region. In addition, these support technology and innovation transfer between enterprises in a region. Interactions and cooperation are strengthened. Here, stakeholders and strategies of knowledge-based regional development are decisive.

**Add-On-B-Indicator – Regional Cluster and Network Initiatives** The indicator measures whether there are efforts of regional economic development to promote cooperation and synergies in the region. In business sectors with outstanding technological competencies there is often enormous potential for transfer between research and industry. The establishment of regional initiatives and networks offers valuable contacts and creates synergies. Thus, cooperation is encouraged, which strengthens the innovative capability and competitiveness of regional enterprises in a region. Intermediaries of knowledge-based regional development as well as universities, R&D institutions and knowledge-intensive enterprises act here as stakeholders.

**Add-On-B-Indicator – Home Institutions of Enterprises of the Knowledge-Intensive Business & Medium-High-Tech-Business Sector** The origins of knowledge-intensive & medium-/high-tech enterprises are measured. To tap the potential of future innovation- and technology-orientated entrepreneurs and spin-offs, information about the home institutions of the founders are relevant indicators. Stakeholders here are universities and R&D institutions, established knowledge-intensive enterprises as well as stakeholders and strategies of knowledge-based regional development.

To conclude, the extended set of indicators has been developed by using the hexagon model. Regional innovative capability is now described by 19 individual indicators, including seven Add-On-Indicators.

## 4 Evaluation

The extended set of indicators covers very different facets of regional innovative capability regarding the core of the hexagon model: social interaction and cooperation. The biggest challenge still is the availability of regional data. In the main thesis by the first author the extended set of indicators has been tested for its functionality in the Aachen region in Germany [14]. All key indicators as well as the Add-On-B-Indicators could be queried on regional level. Exceptions are the Add-On-A-Indicators “Public R&D expenditures”, “Venture-Capital” and “Enterprises innovating in-house”, which are impossible to query through public open data, but still are important to portray regional innovative capability as extensively as possible. For some indicators, however, it has also to be noted that regional data were provided exclusively for scientific purposes. At this point, attention is drawn to possible complementary empirical studies that complete the missing data in the application to other regions.

Overall the Aachen region shows many distinctive characteristics of indicators that suggest being an innovative capable region. Regional innovative capability can therefore be portrayed with the developed broader approach, although more detailed statements about the innovative capability of a region are not possible here: The interpretability of these collected data is restricted due to missing observation spaces, data series and a further consideration of comparable regions.

## 5 Summary and Outlook

Whether the extended set of indicators is able to portray regional innovative capability, at least at the example of the Aachen region, an option to push its validity is the ongoing evaluation of this set of indicators on other regions in the meaning of long-term studies. Another further step is the development towards a full measurement and control tool of knowledge-regional development by considering these missing aspects and by weighting the individual indicators. Finally, an index value of all indicators can also be formed in such a way whereby a direct comparison of different regions is allowed. The development of this set of indicators towards a measurement and management tool will allow more accurate statements about the innovative capability of a region.

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# A Multifunctional Telemedicine System for Pre-hospital Emergency Medical Services

**Sebastian Thelen, Marie-Thérèse Schneiders, Daniel Schilberg and Sabina Jeschke**

**Abstract** The paper presents the design and architecture of a multifunctional telemedicine system for real-time teleconsultation in pre-hospital emergency medical services (EMS). The application of telemedicine has shown to improve patient treatment quality and efficiency in various settings. Still, its use by pre-hospital EMS is lacking. Current technical, normative standards do not provide a sufficient framework in order to design a multifunctional telemedicine system for teleconsultation in pre-hospital EMS. Starting with a use-case driven requirements analysis, a telemedicine system usable in this setting is designed, realized and currently in use for evaluation by selected German EMS departments. This system uses commercial off-the-shelf medical devices, custom devices for communication and an individual system architecture, integrating the heterogeneous components as required by the defined use-cases.

**Keywords** Telemedicine · Teleconsultation · EMS · System Architecture

## 1 Introduction

Specialized telemedical applications have shown to improve patient care in different inner-clinical settings and its benefit has already been demonstrated for various pre-clinical uses [1–3]. Despite the rapid evolution of personal mobile communication devices with its current manifestation of power-full computing devices like smartphones, tablets or even wearable computing-devices [4], the use of telemedicine in pre-hospital environment is still in its infants.

Research efforts have been undertaken to develop multifunctional telemedicine systems which enable emergency medical service (EMS) teams to perform teleconsultation with remote specialists or more broad treatment facilities like hospitals [5–8]. These projects aim at creating pervasive assistance systems using different

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combinations of audio and video communication, transmission of biomedical data and access to existing medical patient records.

The above systems do only allow teleconsultation from inside the ambulance and the additional devices they introduce do not integrate well into commonly used, existing EMS team equipment. System architectures are proposed which require big parts of the created infrastructure to be classified as a medical device and as such pose a high burden on their realization from a regulatory point of view. Another concern neglected by these approaches is the user role which serves a teleconsultation request and thus guides the EMS team during patient treatment or supports them otherwise.

The German research project TemRas has developed the multifunctional telemedicine systems, described in this paper, which allows on-scene EMS teams to consult a dedicated EMS physician, hereafter called tele-EMS-physician, on duty in a teleconsultation center [9, 10]. This system's novelty is its level of integration into the EMS team's equipment and ease of use, enabling teleconsultation not only inside or close to the ambulance but from every location with suitable mobile network coverage, like inside a patient's home. On August 1st, 2012 the system was taken into service with initially three ambulances connected for teleconsultation in regular EMS missions. After a ramp-up during August, six ambulances from different EMS departments were connected to the system and operational since the beginning of September. Until October 4th, 60 successful teleconsultations have been performed using the presented system.

## 2 Method

The system's design was created in a mainly linear process with strong user participation and close feedback loops between engineers and users. The original intent of a true iterative, agile development process could not be realized for the whole system, but was instead used to develop the individual user facing software-components. The whole process was agile in that it was not artifact centered and no sign-offs were performed like described by the waterfall-process [11]. Rather, all process activities were focused on the final system being usable for teleconsultation and fulfilling necessary safety requirements. Documents were only generated as basis for further discussion and swapping functionality in and out of development focus was possible during the whole process.

Involved into the system's design process was a team of experienced emergency physicians, most of which had already been working as tele-EMS-physicians during the former project Med-on-@ix [12]. On one hand they are users to the system as tele-EMS-physician, on the other hand they were user representatives for the on-scene EMS personnel. The participating physicians had used the system on-scene during Med-on-@ix evaluation and had regular contact to relevant EMS personnel during their work as regular EMS physicians. The system design itself was created by a small team of engineers which also realized most of the currently available prototype; other parts were sourced out to specialized hardware manufacturers.

The emergency physicians defined four main scenarios for the telemedicine system's usage. Together the emergency physicians and engineers described and detailed 21 use-cases as functional requirements descriptions to guide the system's design. These use-cases define which services the system has to provide in order to be usable for the main scenarios and roughly describe their usage and inter-relationship. The use-case's descriptions contain additional non-functional requirements like demands regarding robustness, reliability and data security. Service interface specifications were created in close iterations by the engineers and user facing functionality was created in a mockup-driven process with continuous user involvement. As single service's functionalities were available, users were involved in initial testing and requirements and further design was adjusted according to their feed-back.

Integration and system-tests were performed as early as possible in the process to unveil integration issues, missing necessary and planed unnecessary functionality early on. The early system-tests allowed for a good judgment about the actual relevant functionality for the systems intended scope and allowed the development team to react accordingly.

## 3 System Design

The multifunctional telemedicine system's design is subject to some project related invariants which had influence on the development process and the overall system design:

- The system was designed and built during the project's first 2 years and had to be ready for use after that phase in order to allow for its evaluation in regular EMS missions.
- All medical devices used by the system are provided by the associated project partners Philips HealthCare and 3M. Devices from other vendors were not considered for initial integration.

### *3.1 Use-Cases and Main Requirements*

The defined use-cases can be clustered into three main groups which are further detailed in Fig. 1:

- Audio Communication
- Data Transmission
- Common Activities

Besides these main use-cases multiple support use-cases were created to address aspects like user authentication or system administration and are not specific to this telemedicine system.

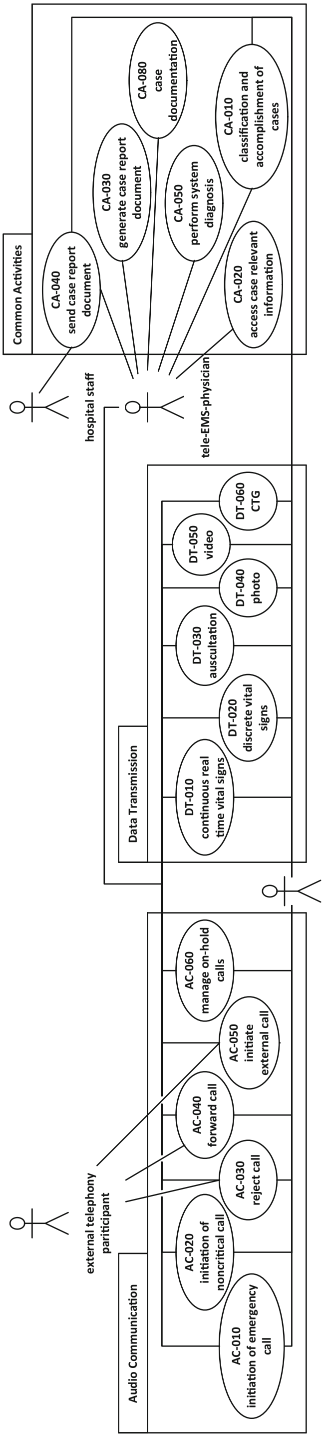


**Fig. 1** The main use-cases defined for the telemedicine system described in this paper

The prominent notion of audio communication related use-cases is based upon existing experience by the involved system users and user representatives, showing that an easy to use, reliable and robust method for bidirectional voice communication between the tele-EMS-physician and the on-scene ambulance team is the single, most important factor for a successful teleconsultation. Making regular phone calls is necessary for the tele-EMS-physician in order to support the on-scene team in administrative tasks or to contact external specialists like the poison control center. To provide a good usability, the tele-EMS-physician has only a single phone-like interface which integrates handling of internal calls (to the on-scene team) and calls to the public switched telephone network.

All use-cases describing the transmission of case related information between on-scene and the tele-EMS-physician are grouped together in the Data Transmission cluster of use-cases. This contains transmission of continuous real-time or discrete biomedical signals, auscultation streams as well as photo and real-time video transmission. The cardiotocography (CTG) is covered as a special form of biomedical signal transmission; it will only be used to perform a smaller study regarding its usability in pre-hospital EMS and does not have any impact on the current system design.

Common Activities mainly contains use-cases describing the electronic case documentation performed by the tele-EMS-physician and the handling of reports automatically generated from that data. The easiest method of delivering a case report to the receiving hospital, together with the treated patient, is by printing the case's summary report on a printer inside the ambulance. Using fax, a report can be sent to the hospital before the patient arrives. Direct integration with a hospital's information systems is currently outside the described system's scope.

The top four non-functional requirements defined for the system are:

- overall system usability
- security of transmitted data regarding eavesdropping
- data correctness
- robustness of both data transmission and audio communication.

Overall system usability is a very fuzzy formulation. This requirement targets at providing an integrated system experience in order to enable simple workflows during patient treatment. To further concretize this requirement, the system's two main usage locations, on-scene and teleconsultation center, are addressed in separation:

- On-scene the ambulance team's current workflows and carrying pay-load should be influenced as little as possible. The system must seamlessly integrate with the devices used on-scene and be usable for a regular two-person team during potentially stressful patient treatment.
- From the teleconsultation center one tele-EMS-physician only interacts with one ambulance team at a given time. All related services must ensure that data only from that team is displayed. The different services must integrate seamlessly into one working environment in order to reduce the burden posed onto the tele-EMS-physician by the system's usage.

Data correctness covers two main concerns:

- Information must not be altered between its acquisition on-scene and presentation thereof to the tele-EMS-physician. If data is transformed in any way it must be ensured that the information it presents is not affected by that transformation.
- It must be ensured that data which is presented to a tele-EMS-physician is at any time associated to the correct ambulance and thus the right patient respective case.

### *3.2 System Architecture Overview*

Various harmonization and standardization groups have defined different standards and interoperability profiles, a collection of specifications often with accompanying restrictions and definitions, for a multitude of data-interchange and device integration scenarios: Health Level 7 (HL7), Integrating the Health enterprise (IHE), Continua, IEEE 11073 [13–15]. The amount of different, sometimes competing, sometimes complementary specifications and usage profiles makes it hard to know where to start when looking for the right design for a system which does not fully fit the existing use-cases. At the same time the harmonization efforts mainly target the hospital or consumer market. A market survey regarding pre-hospital EMS devices shows that by now first manufacturers begin selling telemedicine enabled devices, with each vendor creating an independent, proprietary solution [16, 17].

Based on the use-cases, additional requirements and project constraints, a system architecture was designed. This process started by choosing the devices which compose the on-scene system. This device-centric view onto the system is depicted in Fig. 2 in which the system is divided into the three locations: consultation center (top), ambulance/in-car (left) and on-scene (right). All data transmission from inside the ambulance and on-scene is relayed to the consultation center via a special data transmission unit (peeqBOX, designed and manufactured for use in this system by P3 Communications GmbH, Aachen, Germany).

The in-car peeqBOX acts as gateway for the Local Area Network (LAN) inside the ambulance, enabling TCP/IP network traffic between this and the consultation center's LAN. The following devices connect directly to the ambulance LAN:

- A network enabled video camera (SNC-RZ50P, Sony, Japan) is mounted at the ambulance's ceiling. It is fully controlled by the tele-EMS-physician who can tilt, pan and zoom its view. The video is streamed using a H.264 video codec, eight frames per second, a Bit rate of 128 Kbps and an image resolution of 384 times 288 pixel.
- A thermal printer (PocketJet PJ-623, Brother, Japan) with 300 dots per inch using a print server (TL-PS110U, TP-Link, China) for its connection to the network.

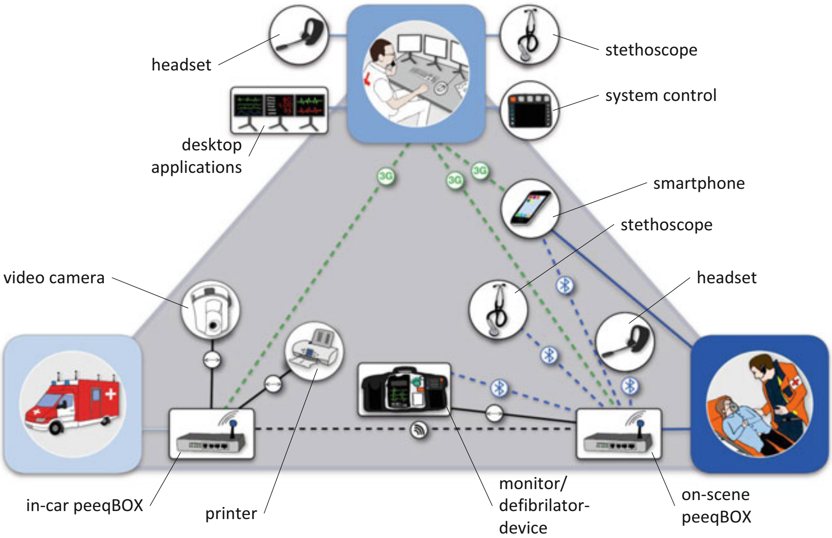


**Fig. 2** Device-centric view on the telemedicine system's system architecture. (Adapted from [9])

The on-scene devices all use Bluetooth to wirelessly connect to the on-scene peeqBOX. This peeqBOX itself is housed inside the right pocket of the monitoring/defibrillation device, as shown in Fig. 3. The following devices comprise the on-scene location of the system:

- A monitor/defibrillator-device (HeartStart MRx M3535A, Philips, Netherlands) configured with the options SpO2, NBP, EtCO2, 12-Lead, 12-LTx Bluetooth, Pacing, Q-CPR, Q-CPR Data, 75 mm Printer, EventSum Bluetooth, IntelliVue Net and Per Data Tx.
- Two headsets (Plantronics Voyager Pro HD, Plantronics, USA) used by the ambulance team to communicate with the tele-EMS-physician. This communication link is delivered via a regular voice call established by the on-scene peeqBOX using public circuit switched mobile telephony networks.
- A smartphone (HTC Sensation XE, HTC, Taiwan) serving two purposes: In regular operation it is used to take photographs on-scene which are automatically transmitted to the consultation center. In case of the loss of the regular audio connection via the peeqBOX during a case, the ambulance team can directly call the tele-EMS-physician with this phone, increasing the chance for safe termination of a consultation instead of its interruption.
- A stethoscope (3M Littmann electronic stethoscope 3200, 3M, USA); this device's integration is still in its conception phase and is not used by the currently running system.

**Fig. 3** An early development prototype of the on-scene peeqBOX fitted inside the right pocket of the monitor/defibrilator-device's bag. The bag's right pocket was later adjust to provide space for patient therapy equipment

In the consultation center a tele-EMS-physician's workplace is comprised of the following user-facing devices, as shown in Fig. 4:

- A wireless headsets (Savi W710/W730, Plantronics, USA); the tele-EMS-physician can choose out of two available models which one to use or switch the headset if the first one runs out of battery power.
- A stethoscope (3M Littmann electronic stethoscope 3200, 3M, USA); this device's integration is still in its conception phase and is not used by the currently running system.
- A desktop computer (OptiPlex 780 DT, Dell, USA with main memory: 4 GB; processor: Intel Core 2 Duo E8400, Intel, USA; graphics-card: NVIDIA Quadro NVS 420, NVIDIA, USA) with three monitors (UltraSharp 2007FP, Dell, USA) attached running Microsoft Windows 7 operating system hosting the different applications used by a tele-EMS-physician during consultation.

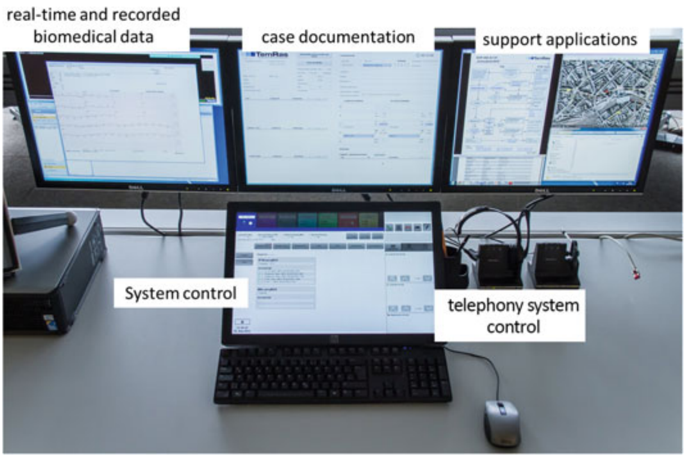


**Fig. 4** Photography showing a tele-EMS-physician workplace with the three top monitors showing the main applications (besides video) used during a consultation and the lower centered touch-monitor with the system control interface and the integrated telephony system controls to the right. Keyboard and mouse are connected to the desktop computer to interact with its applications on the three top monitors

- A dedicated control computer (OptiPlex 780 USFF, Dell, USA with main memory: 4 GB; processor: Intel Core 2 Duo E8400, Intel, USA) with a single touch monitor (Elo 1900 L APR, Elo, USA) attached which is used to control the telemedicine system, shows data for system diagnostics and offers an integrated user interface for the telephony system.

### 3.3 Device and Service Integration

Classifying the devices by the Continua Alliance's Reference Architecture, the monitoring device and stethoscope are Peripheral Area Network (PAN)- or LAN-devices whereas the on-scene peeqBOX is an Application Hosting Device [14]. All services provided by the tele-EMS-physician relate to WAN-devices. Storage of patient related information could be delegated to a Health Record Device (HRD), but such a service's primary intend of "... offering a broad overview of a person's health status in a central location [18]" is out of the scope of the current system design.

Current state of the art would suggest realizing the connection between said PAN-devices and the on-scene peeqBOX by following IEEE 11073 family of standards [15, 18]. Two current facts prevent this choice:

- Only a subset of the necessary device profiles exist as approved standards: blood pressure monitor and pulse oximeter, whereas basic electrocardiogram (ECG), using 1- to 3-leads, is still in final draft status by ISO [19–21]. Communication of 12-lead ECG or stethoscope connection has not been addressed by this family of standards at all. (reason might be focus of use-case)
- None of the devices in question for use supports an open standard for communication. The only way to interface with them is by means of proprietary software provided by the devices vendors.

Instead a common integration approach is used by building a message driven middleware layer following common Enterprise Integration Patterns [22] using individual adapters to control the used third party applications. This middleware layer is comprised of different Java services hosted on a Java application server (Glassfish v3.1.2, Oracle, USA). Messaging is performed via the Advanced Message Queuing Protocol using a single message broker (RabbitMQ v2.7.1, VMware, USA), enabling service adapters to be implemented in different programming languages. The system's user interface presented to a tele-EMS-physician is composed of both preexisting local applications running on the desktop computer and rich web applications specifically implemented for this setting.

The web applications displayed in a special viewer application instead of a regular browser, allowing tight control over them and preventing the user from accidentally navigating away from an application. These viewer applications as well as the other local applications are controlled by an application controller service running on the desktop computer, allowing the middleware services to launch, close or otherwise remote-control them.

All but the system's audio communication functionality uses IP network technology to connect the ambulance (in-car) and on-scene location to the consultation center [23]. This IP network is provided by each of the peeqBOX-devices, simultaneously using multiple third generation mobile telecommunications network links, up to three on-scene and up to five in-car to connect to a special router, called Stationary Communication Unit (SCU), in the consultation center. Additionally the in-car peeqBOX offers a Wireless LAN (IEEE 802.11a) inside and close to the ambulance which is used by the on-scene peeqBOX to relay all its IP network traffic via the in-car peeqBOX and its roof-mounted antennas. All IP network traffic between the peeqBOX-devices and the SCU is distributed among the available mobile network connections and encrypted using AES-265 encryption. This approach enables direct integration of IP network capable services (video-camera, printer) and at the same time ensures a high robustness against the full loss of their network connection.

On top of the IP network each peeqBOX offers a file transfer service using the standard File Transfer Protocol. Via this service files are delivered to ambulance specific inboxes where they are further processed by the middleware layer and handed to consuming services in the consultation center. Access to this file transfer service is offered by additional peeqBOX service adapter:

- The photo adapter queries pictures taken with the smartphone via the Bluetooth File Transfer Profile (Bluetooth FTP), having the smartphone act as server. As soon as the adapter has handed a picture to the file transfer service, it deletes the picture on the smartphone.
- The biomedical signals adapter accepts Bluetooth FTP connections from the monitor/defibrillator-device which uses this method to publish files containing periodic trend data and recorded 12-lead ECGs, both in a proprietary data format.
- System diagnostics data concerning a peeqBOX is collected into a small sized (less than 600 Byte) XML-file every 10 s and handed to the file transfer service. This data includes: battery level (only on-scene), device temperature, voice and data connection overview, detailed mobile connection link data, headset status, time-stamp and global positioning system (GPS) coordinates.

To enable continuous real-time biomedical signal transmission from on-scene the peeqBOX uses an OSI Layer two network bridge to connect the monitor/defibrillator-device to the clinical network provided by an IntelliVue Information Center (Philips, Netherlands) in the consultation center [23]. The monitor/defibrillator-device's integration will be discussed in more detail in a future publication.

The audio communication between on-scene and a tele-EMS-physician is realized in two stages. The on-scene peeqBOX is used as multi-SIM mobile phone with additional control logic. The user interfaces to this function only by using the single button on its headset, which initiates an emergency call to the consultation center via the best available, circuit switched network. In the consultation center a private branch exchange based on the open-source Asterisk framework answers the call by putting it into a separate conference room. The tele-EMS-physician which accepts such an incoming call is connected to this conference room via a voice over IP client, remote-controlled via the system's middleware layer. Using the touch monitor's telephony interface, the tele-EMS-physician can itself initiate calls either to an on-scene peeqBOX or to an external telephony participant.

## 4 Conclusion and Future Work

A multifunctional telemedicine system using commercial off-the-shelf medical devices, which is suitable for use by a regular EMS team, has been presented in this paper. The lack of existing standards for the required integration of medical devices results in an interoperability issue which prevents the creation of open systems and common frameworks or platforms for such a telemedicine system. The current situation requires integrating each device or product line independently. Solving this interoperability issue should therefore be a primary target of future research and regulatory efforts.

The presented service integration approach using a simple message broker enabled a rapid system implementation and proved suitable for creating an integrated telemedicine system. Its capability for delivering sophisticated, automated workflows, e. g., for advanced reporting or data-exchange with external entities, however is limited. The use of concepts like Enterprise Integration Bus might be a viable option to address this issue and is left for future work.

Integrated information exchange with receiving hospitals or electronic health records is not covered by the scope of the presented research. The IHE and Continua Alliance efforts generally address this concern. Assessing their existing guidelines regarding suitability for this integration use-case remains for future work.

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# Detecting Central Research Results in Research Alliances Through Text Mining on Publications

**Thomas Thiele, Claudia Jooß, Florian Welter, René Vossen, Anja Richert and Sabina Jeschke**

**Abstract** Not only in the German research landscape, the establishment of research alliances has become a key element of the national funding structure, especially in order to address current societal, economic and scientific problems. These complex problems are mutually investigated by heterogeneous actors whose heterogeneity can be mainly seen in a combined research effort of scientific as well as business-driven research – a so-called transdisciplinary research approach. The main challenge which arises from this approach covers the cooperation of numerous actors in a complex and often intransparent collaboration structure. To allow transparence of the central research topics within these structures, publication data has to be consolidated and classified.

In order to address this challenge, the establishment of an information management environment supports the ability to handle big repositories of publication data on the one hand and to visualize different thematic interests on the other hand. In this example, fostering cooperation among actors, by revealing thematic accordance, connections and development, becomes possible.

The paper addresses the question in how far an information management environment can support this revealing process by means of classification publication data. Focusing on an information management environment in its pre-prototypic stage, the development process as well as initial results are presented. The results are derived from publication data examined by the transdisciplinary research alliance “Innovative capability in demographic change” initiated by the German Federal Ministry of Education and Research (BMBF).

**Keywords** Information Management · Classification · Transdisciplinary Research

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# 1 Introduction

Meeting societal and economic challenges like the demographic change is one of the major tasks in the upcoming decades [1]. As the demographic change afflicts multiple areas of the societal and economic world, it can also be considered as object of research. In order to address this research scientific efforts are often accompanied by practical partners. As a result, associations of researching actors cooperate in a collocation of different scientific disciplines as well as economic branches and domains in a so-called transdisciplinary research approach [2]. Conducting research by means of this approach requires new methods and instruments of integration between the scientific and economic domains [3]. In this paper, classification is presented as a technical, text mining-based instrument to support the integration in transdisciplinary research (e. g. Sect. 1.1). As this instrument is in a pre-prototypic stage, the development process (e. g. Sect. 1.2) and first results derived from steps of this process (Sect. 2 and Sect. 3) are outlined.

## *1.1 Classification of Publication Data in a Transdisciplinary Research Approach – A Working Definition*

Transdisciplinary research generally focuses on concrete subjects of investigation and, therefore, is typically conducted in highly specialized but temporarily joint research projects [2]. Multiple projects are normally embedded in a transdisciplinary research alliance, which is in turn initiated by sponsoring authorities. The aims of a transdisciplinary research alliance are mostly large-scale research subjects, e. g. the innovative capability in the demographic change, which serves as a case study in this paper (e. g. Sect. 2.1). The additional benefit of a transdisciplinary research alliance can be seen in a combined research effort of scientific as well as business-driven research, which leads to findings usable for the scientific community as well as relevance for practical purposes in an ideal case [3]. Especially as an instrument of integration, the relevance of classification results from the complexity of a transdisciplinary research approach. This complexity can be seen in the formation of large transdisciplinary research alliances as well as the heterogeneity of its actors.

The cooperation of actors with scientific and economic origin requires an agreement on different views, perspectives, and aims in order to enable a combined research effort [3]. Hereby, the heterogeneity of actors as well as a need for integration becomes visible: scientific and business-driven actors have to commit to a common project expecting solutions for both the economic and scientific sector. In order to foster this process, the classification process described in this paper pursues the objective to condense information derived from publication data with the aim to support information flows between the actors in a joint research project as a first step. Welter [4] identifies the support of these information flows between teams and different hierarchical levels as a key attribute of research projects [4]. Defila et al.

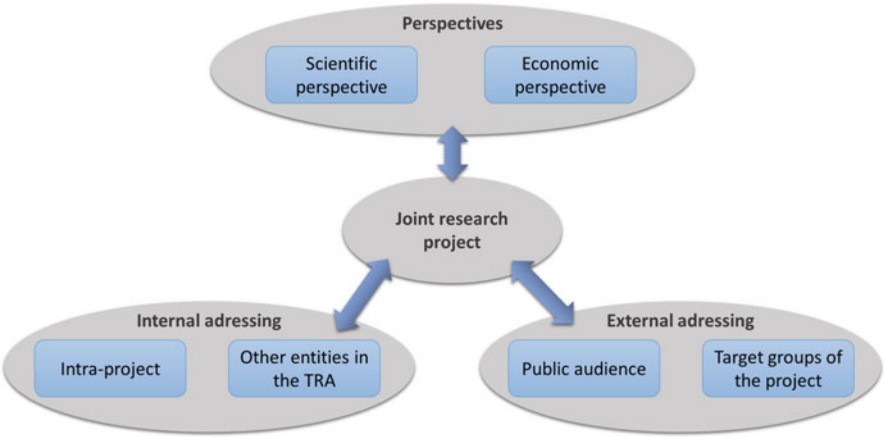


**Fig. 1** Requirements for information flows centered on a joint research

[5] extend this definition beyond an intra-project level and include information flows between a target group as well as a public audience [5]. Regarding the embedment of a research project into a transdisciplinary research alliance, the results of a classification process also have to cover the information flows within the research project itself and other structural elements and entities in the transdisciplinary research alliance, e. g. other research projects and central stakeholders. Hence, for transdisciplinary research alliances, a classification process has to cover different requirements for information flows, which have been visualized in Fig. 1. These information flows can be covered with condensed summaries of information based on publication data suitable for the target audience (e. g. different perspectives, external addressing etc.). Hence, these summaries try to reveal thematic patterns, accordance and development in a transdisciplinary research alliance in order to sensitize for research efforts of the other actors involved and, therefore, support a common understanding of the transdisciplinary research alliance as a whole. In this context, the creation of visualizations derived from this summarized data is a key element of a classification process in this paper.

However, classification processes do not have the ability to function as instruments of integration only by covering information flows. In this context, the relation between signs, data, information and knowledge can be seen as an approach to a further definition of the to be developed classification process. Although the discussion on these fundamental terms is controversial, a working definition in the perspective of this paper is given. The basal level is represented by a simple pool of signs, which consists e. g. of letters and numbers. When signs are implemented in a defined and structured correlation, they can be recognized as data. Following Krcmar [6] information arises, when embedding these data into further relations [6]. The emergence of knowledge from information describes the highest and last step in this model. According to Vossen [7] knowledge arises, when information is evaluated as useful for further actions. This leads to the assumption that knowledge emerges, when information is contextualized, interpreted, classified and connected [7]. On the basis of these definitions information can be used to support the cooperation and a common understanding of research topics among the actors in a transdisciplinary research alliance. In order to serve as an instrument of integration in the context of a classification process this information has to be used to initiate and support further actions. E.g. the above-mentioned information summaries can be the basic concept for the composition of thematic groups in networking events, where individual groups of actors are put together with the aim to initiate further collaboration. Hence, the to be developed classification process is able to foster further ways of integration, as this build-up of alliances can be considered as a field of action for the cooperation support of research alliances [8].

On the basis of this consideration classification in the context of this paper consists of two main parts: the covering of information flows and the usage of these flows in order to foster the integration of a transdisciplinary research alliance. In this paper, the first part is mainly addressed. As the covering of information flows can be interpreted as an application of Information Management (IM), this approach is outlined in the following. IM focuses on information flows in organizations and the transfer as well as processing of information on all hierarchical levels in an organization [9]. Thus, another assignment can be seen in the effective supply of actors with information [6]. As this paper focuses on a system to be designed, which is able to fulfil these assignments, this system is referred to as IM environment.

In dependence on an IM system, which is specified as man-machine systems with the ability to provide communication and information to its users [6], an IM environment can be defined as an open system, which tries to extract the meaning of publication data in order to derive thematic accordance in the analyzed data. As this task can be recognized as one of the basic use cases of text mining [10], this technology might serve as the basal element of the IM environment. In contrast to an IM system the IM environment in its current pre-prototypic state is not able to serve as an application system, which provides a fully automated process regarding the acquisition, converting, saving and transferring of information [11]. However, the functionality of the IM environment comprises the ability to reveal thematic accordance in publication data. The development steps towards this pre-prototypic state are briefly exemplified in the next chapter.

## *1.2 Design Methodology Based on Engineering Design*

The design methodology of the IM environment presented in this paper is derived from a model process mostly used in engineering and software design in order to systemize product development [12]. Advantages of a methodology-based proceeding can be stated by a projectable and reflective approach, which intends to support creativity and problem-based thinking [13]. Referring to a systemic problem solution process this design methodology is divided into six steps in order to complete the product layout (cf. Fig. 2).

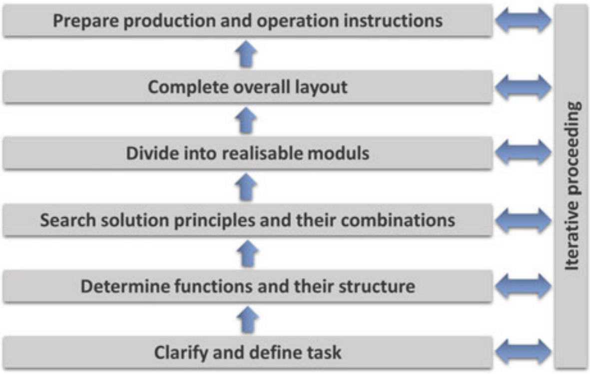


**Fig. 2** Design methodology used for the development of the IM environment [12]

The proceeding between these steps is completely iterative. Thus, findings in further design steps can always affect already completed steps. E.g. the search for solution principles and their combinations can modify the definition of the task as the development of solution principles generally induces new requirements for the whole product.

As a technical approach to develop a classification process shall be discussed, the design of a text mining approach is focused in the next chapters. In order to meet the demands, which have been exemplified in Sect. 1. The requirement analysis as a result of the first development step "Clarify and define task" and initial results derived from the steps "Determine functions and their structure" and "Search solution principles and their combinations" are content of the next chapters.

## 2 Requirement Analysis

As highlighted in Sect. 1.2 the requirement analysis displays the result of the first step in the design methodology used. The composition of requirements in engineering design is often based on guidelines, which have been derived from previous development cycles [13]. The structure of a transdisciplinary research alliance as well as technical conditions (e. g. requirements of the used program and the data format) are exemplified as characteristic features of the analyzed requirements in the context of this paper. These requirements are set up in order to define the framework for an IM environment, which aims to support the revealing of thematic accordance.

### *2.1 The Transdisciplinary Research Alliance "Innovative Capability in Demographic Change"*

The funding priority "Innovative Capability in Demographic Change", funded by the BMBF, serves as a use case for a transdisciplinary research alliance. A detailed analysis of the transdisciplinary research alliance structure provides further insights about information flows, which have to be addressed in the presented classification approach.

The transdisciplinary research alliance consists of 27 joint research projects, which are aiming at an utilization of the demographic change in order to foster societal innovative capability by flexible structures in professional life, an improved collaboration between generations and a continual competence acquisition [14]. Within the 27 projects, there are nearly 194 researching organizations, consisting of about 34 % scientific organizations and 66 % networks and economic partners [15]. With regard to the external addressing (cf. Fig. 1) another structural element has been implemented into the structure of the transdisciplinary research alliance besides the research projects. Six thematic focus groups have been established in order to support the public relations as well as the transfer of results respective to the public audience and target groups. Jooß defines these focus groups as related to the target audience, thematically bundling of the joint research projects in the funding priority [16]. The groups comprise representatives of the research projects, the project executing organization (as a connection to the BMBF) and the metaproject. As another entity in the transdisciplinary research alliance the metaproject takes over the role of a moderator and supports the actors by means of communication and cooperation as well as cross-project activities [15]. The metaproject activities aim at an optimized transfer of results with regard to the internal and external exploitation of scientific findings.

In order to support the cooperation between all of these entities in the complex structure of the transdisciplinary research alliance "Innovative Capability in Demographic Change" a common understanding of the topics of each project and focus group can be considered as basal element. Hence, the approach presented in this paper represents a technical way to enable the revealing process of accordance and the thematic development of this accordance in the life cycles of the projects. Further requirements of the technical framework used in this approach are exemplified in the next chapter.

### *2.2 Technical Conditions and Data Format*

The approach presented in this paper is based on the mining of publication data. With regard to the appliance of this approach the technical conditions in form of requirements to a software tool and the structure of the data to be analysed have to be illustrated. The publication data of the transdisciplinary research alliance "Innovative Capability in Demographic Change" is mainly composed of documents. As a basic element of text mining a document is defined as "a unit of discrete textual data within a collection that usually, but not necessarily, correlates with some real-world document" [17]. In the context of this paper, the results are derived from a collection of documents, which has been published as a common transdisciplinary research alliance publication. Following the definition of Feldmann and Sanger the documents in this collection can be considered as weakly structured as there are "strong typographical, layout, or markup indicators to denote structure" [17]. Hence, all of the 27 projects as well as the focus groups participated in this publication. On the basis of a participation of all actors in the transdisciplinary research alliance this collection represents a state of the art research of the transdisciplinary research alliance, when it was published in May 2013. In order to reveal thematic accordance, the collection stored in the form of a PDF-file has to be analyzed and processed with the aim to create a visualization. This shows a thematic summary of the analyzed entity (e. g. a research project or focus group).

Hence, the software tool has to fulfil two primary requirements: initially and as basal element the collection of documents must be readable and processible by the software. Furthermore, each document in the collection has to be identifiable after processing in order to enable an assignment of the derived visualization (e. g. to a research project or focus group). Therefore, the processed publication data has to be enriched with metadata, which allows this assignment. Regarding the extensibility of the software tool a modular process design in the software is appreciated. This modular design supports the idea of an open IM environment (cf. Sect. 1.1) as this environment shall be capable of accessing and processing different storages of publication data. As a second primary requirement the software tool has to be able to create visualization as a form of the processed data. This supports the idea of creating a condensed summary of information in a classification process (cf. Sect. 1.1) as visualizations are able to carry a high variety of information and therefore represent an efficient means of transporting information [18]. Since further specifications of the demanded visualization have not been determined yet, the software tool has to offer a wide range of visualization capabilities. Moreover, it provides interfaces for a continuing use of processed data in other tools in case these capabilities are not sufficient.

## 3 Initial Results

As further findings initial results of the steps "determine functions and their structure" and "search for solutions for solution principles and their combinations" are presented in this chapter. Based on the requirement analysis a function structure has been lined up in order to meet and substantiate the demanded functionalities (cf. Sect. 3.1). Moreover the solution principles, which have been derived from the function structure, have been implemented into a software tool and therefore led to a first revealing of accordance by analysing the publication data mentioned in Sect. 2.2. Hence, an exemplified visualization, which illustrates the principles behind the revelation, is presented in Sect. 3.2.

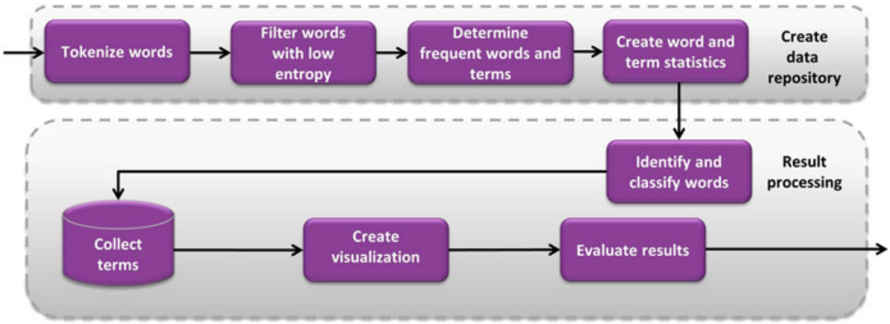


**Fig. 3** Process of creating common term connections in two steps (on the basis of [19])

## 3.1 Function Structure

As text mining is the basal technology of the above-mentioned revealing process, an explanation of this technology can be found in the following definition: "Text mining aims at disclosing the concealed information by means of methods which are able to cope with the large number of words and structures in natural language on the one hand and allow to handle vagueness, uncertainty and fuzziness" [19] on the other hand. Following this definition, the revealing process has to comprise methods, which create a data repository that structures large numbers of words as a preprocess before the actual results can be processed. As the design methodology displayed in Fig. 2 recommends the determination of functions and their structure, a function structure of the whole procedure as well as the pre-process (cf. "Create data repository") is visualized in Fig. 3. Here, tokenizing the words is the first step to transform the unstructured text into a machine readable form by splitting up the text into fragments [20]. The following step implements a filtering function in order to remove words with low entropy and, thus, only minor information content. Subsequently, the frequency of words and terms is counted and processed into a statistic.

The result of this "Create data repository" pre-process is used in the following functions of the "Result processing" step, which builds up a frequency vector of the word and term statistic by using a tf-idf algorithm[1] and further necessary sub-steps in order to create a collection of frequent item patterns. As this algorithm provides a condensed form of the information gathered in the previous steps, a repository of collected terms is produced. This condensed information can be further disposed in order to create association rules between the items [21] or serve as basic data set for visualization. As the next steps in Fig. 3 focus on visualization used for an instrument

[1] The tf-idf vector represents an approved algorithm in order to create frequent item sets in large amounts of texts. As this article emphasizes the application of text mining in the given context, reference is made to [22] and [23].

to evaluate the processed data with the aim to reveal accordance in the form of term connections, such a visualization is presented in the following chapter.

### *3.2 Reveal Thematic Accordance by Visualizing Term Connections*

First results have been derived from the collection of documents mentioned in Sect. 2.2 by using the process displayed in Fig. 3. This process has been implemented into the software tool Rapidminer in version 5.3[2]. In this example, five documents of a focus group as an entity in the transdisciplinary research alliance "Innovative capability in the demographic change" have been analyzed. In order to disclose thematic accordance in this focus group, a scatter plot (cf. Fig. 5) visualizes exemplarily the appearance of the term "innovative capability" in connection to various other terms, which have been referred to in the latter publication. While each dot represents a document in the analyzed publication, the color of the dots in each square indicates whether the term „innovative capability" occurs (red) or not (blue).

In order find further correlations, a detailed description of the axis as well as the meaning of the diagram is provided in Fig. 5. Each axis is labeled with a term (e. g. "older" and "employees"). The two values of the axis (either "true" or "false") and the position of the dots indicate if the term is mentioned in the analyzed publication. The interdependance between two terms is displayed on the intersection of each axis: Regarding Fig. 4 the connection of innovative capability and "older" (on the horizontal axis) as well as "employees" (on the vertical axis) is illustrated. As five texts of the above-mentioned publication have been analyzed, five dots appear in the diagram showing two blue dots and one red dot on the intersection of the "false" axis and another two red dots on the intersection of the true-labeled axis.

The result that innovative capability is mentioned in the context of "employees" as well as "older" in 40 % of the sample may lead to the assumption, for instance, that the innovative capability of older employees is researched in context of the focus group, which has been analyzed here. Further terms and their coincidences will offer even more thematic accordance and will lead to a full overview of the discussed topics in the focus group. To create this overview a variety of scatter plots combined into a so-called scatter matrix is necessary. As an example the excerpt of a scatter matrix generated on the basis of the above mentioned data is visualized in Fig. 5.

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[2] According to [24] Rapidminer has been voted amongst the first open source text mining tools by the www.KDnuggets.com poll in 2013. As Jungermann states, Rapidminer has already won this poll in the past [20].

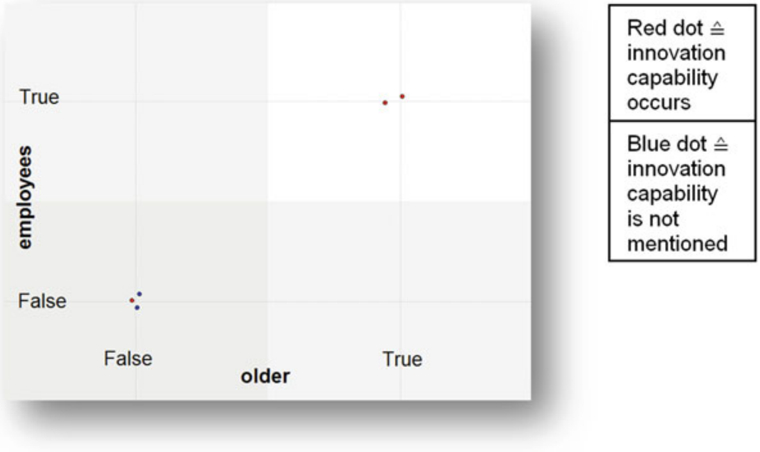


**Fig. 4** Detailed diagram description: Coherence between “older”, “employees” and “innovation capability”

### *3.3 Discussion of Initial Results*

In the given example, thus, the findings might be used in order to determine the thematic adjustment of the focus group. However, these first examples still require further validations in order to allow a significant interpretation. On the one hand, these examples can be enriched by deeper data analysis, using the function structure mentioned in Sect. 3.1. In this context, the implementation of a so-called FP-Tree, which is originated from a FP-Growth algorithm [25], displays weighted links between terms. These links might be used in order to validate the scatter plot diagram. On the other hand the enlargement of the sample to more than five documents will provide a more detailed perspective as there will appear more dots, which will minimize the risk of misinterpretation due to a higher universe. Moreover, a higher quantity of documents will allow to use the full potential of the text mining approach [17].

## 4 Conclusion and Outlook

In the present paper, a classification process has been defined in two steps in the context of a transdisciplinary research approach. The first step is concerned with the development of an IM environment, which is able to derive information summaries of processed publication data. The development process of this IM environment in combination with a text mining based approach has been outlined in the last chapter. Based on this processed data a scatter plot has been presented in order to reveal

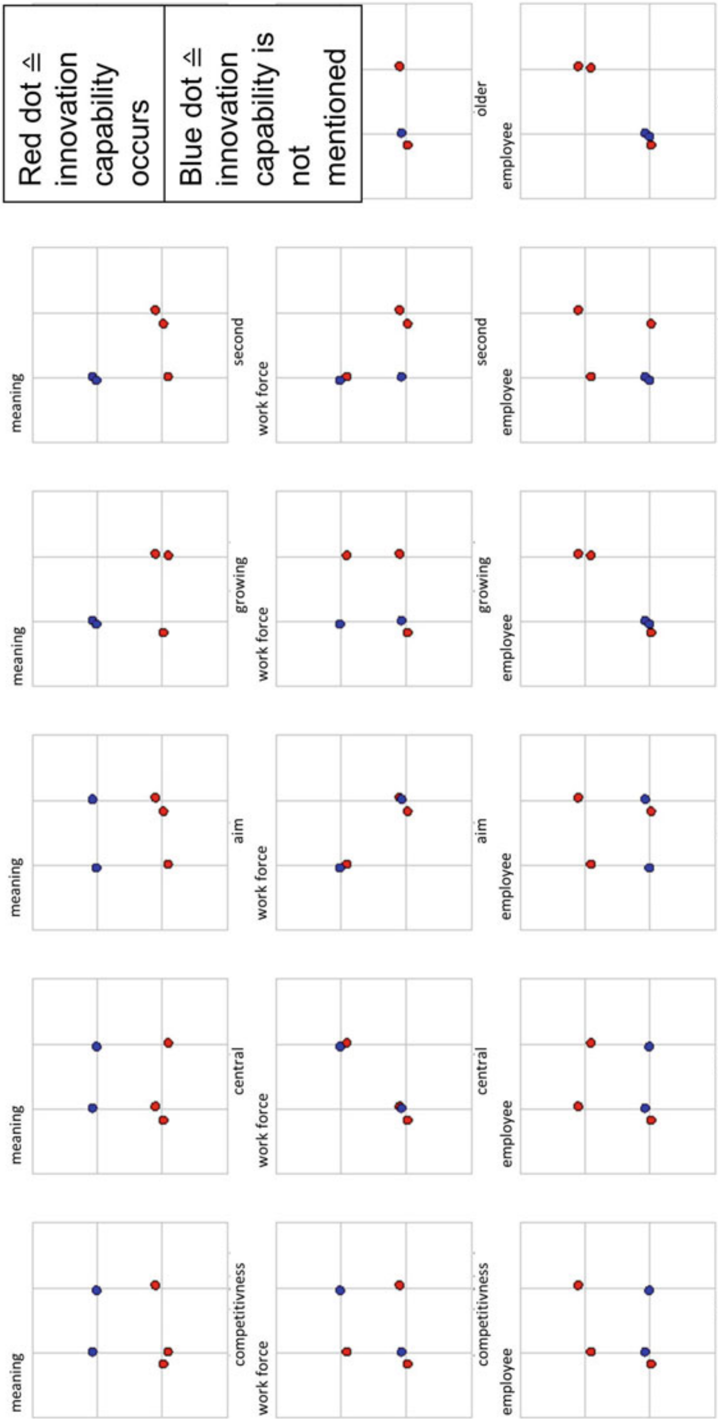


**Fig. 5** Excerpt of a scatter matrix

thematic accordance in an entity of a transdisciplinary research alliance. As has already been stated in the introduction, the above-mentioned IM environment is in a pre-prototypic state. In order to discover the impact of this approach further research is necessary, which addresses the question in how far the integration of a transdisciplinary research alliance is affected by the presented classification process approach. Concerning the technical development of an IM environment, a continuing analysis of publication data is required aiming at a set of visualization. These visualizations may show the thematic development of the whole transdisciplinary research alliance and in particular the development of various entities in the transdisciplinary research alliance. For this, further measures have to be developed, which have the ability to derive innovative and valid visualization of this thematic development. To achieve this goal not only technical means have to be focused. Rohrdantz et al. state that the integration of human experts is also necessary in order to minimize the uncertainty of automated systems [26]. Hence, further development will extend the IM environment to a combined human-machine approach.

**Acknowledgements** This work was supported by the German Federal Ministry of Education and Research (BMBF) under Grant 01HH11088 and was co-financed by the European Social Funds (ESF).

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# Design and Development of a Business Model for Less Than Truck Load Freight Cooperation

**Nadine Voßen, Phil Friedrichsmeier, Eckart Hauck and Sabina Jeschke**

**Abstract** In times of globalized markets growing cutthroat competition compels companies to continuously identify new optimization potentials along their supply chain (Killich and Luczak, Unternehmenskooperation für kleine und mittelständische Unternehmen, p. V, 2003). In particular small and medium sized logistic service providers suffer from this development and lack the resources and geographical reach as well as the required quantities of customer shipments (Klaas-Wissing and Albers, Int J Logist Res Appl 13, p. 494, 2010).

Freight cooperation offers new alternatives for logistic service providers to assert their position against big competitors by bundling shipments of several participating logistic service providers and thereby, generating synergetic effects. Successful cooperation already exists in terms of general cargo and full truck load situations. Yet, in the case of Less than Truck Load shipments, no comparable solutions are available today. Usually not enough shipments with similar dispatch or receipt places exist, which leads to a small rate of return per truck (Tummel et al., Proceedings of the 3rd International Conference on Logistics and Transport & the 4th International Conference on Operations and Supply Chain Management, p. 2, 2011).

Hence, a suitable business model for a Less Than Truck Load freight cooperation is needed which is based on an IT-based central disposition, while in the meantime utilization rates are maximized and the number of empty runs is reduced (Bretzke, Logistische Netzwerke, p. 334, 2010). In addition, adequate fairness models and incentive concepts are fundamental requirements which have to be covered by the business model in order to overcome doubts of potential participants and to guarantee a successful cooperation.

In this paper we describe the development for a Less Than Truck Load business model, which is developed by the Project “Cloud Logistic” funded by the state North Rhine-Westphalia of the Federal Republic of Germany and by means of the European Regional Development Fund (ERDF). For the development we apply a combination of the Business Model Canvas (Osterwalder and Pigneur, Business Model Generation, p. 14, 2009) and a trend-based scenario technique, which enables us to create future scenarios and to derive action plans. Thereby, we establish a robust

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and sustainable business model for freight cooperation networks in the Less Than Truck Load segment.

**Keywords** Freight Cooperation · Logistic Service Provider · Business Model · Scenario Analysis

## 1 Introduction

A recent study of the German Federal Ministry of Transport, Building and Urban Development [1] forecasts a significant increase of traffic volume until 2025. Especially the development of the long-haul road transportation will be faced with an increasing transport volume of about 55 % and a general increase of traffic of about 84 %. In contrast to rising fuel costs and an increasing pressure through tougher environmental regulations every fifth truck in commercial freight traffic is still driving without any load at all [2].

Small and medium logistic service providers (LSPs) suffer from these trends and have to find new ways in order to sustain competitive in the market. To realize synergy effects, different logistic service providers merge with competitors and build horizontal cooperation in the road freight transport market. These cooperation enable logistic service providers to improve their service levels and their own market position through an increase of geographical reach [3, p. 23]. Freight exchanges represent a successful solution for the general cargo and Full Truck Load segment. For the segment of Less Than Truck Load no similar concept exists. But especially Less Than Truck Load shipments are very uneconomic because they do not fully utilize a common truck or rather shipment-turnover prohibitions by law or customer demands recently impede an efficient handling of these shipments [4, p. 1057]. In particular the strengths of already existing general cargo and Full Truck Load networks should be transferred to the area of Less Than Truckload transports.

The challenge is to develop a flexible business model for a Less Than Truck Load freight cooperation which can be adapted to external changes like for example technological innovations, financial crisis, and new customer preferences. Therefore organizations have to implement a structured process of business model generation on the one hand, and on the other hand they have to establish a structured business model change process to realize long-term strategy which is sustainable even against future external market changes.

Funded by the state North Rhine-Westphalia of the Federal Republic of Germany and by means of the European Regional Development Fund CloudLogistic focuses its research on the development of an innovative logistics concept for a Less Than Truck Load freight cooperation in order to strengthen the market position of Small and Medium-sized logistic service providers [5, p. 2]. For a successful development of such a logistics concept the construction of a flexible and suitable business model is required.

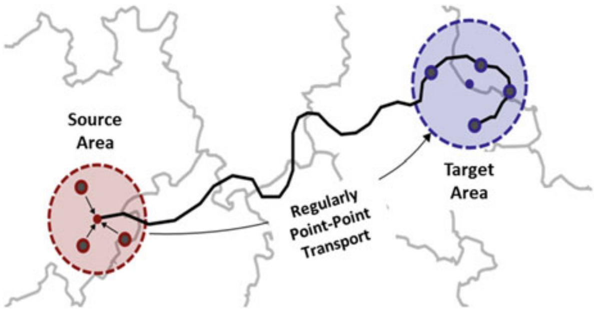


**Fig. 1** Example of a freight route as a relation between a source and a target area. (Source: [6])

The remainder of the paper is organized as follows. In Sect. 2 we introduce the CloudLogistic-Scenario and the main objectives of the research project. In Sect. 3 the requirements for a business model of a Less Than Truck Load freight cooperation are presented. After the identification of these requirements an initial design concept of a Less Than Truck Load business model based on the Business Model Canvas method is presented. Furthermore, in this chapter the trend-based scenario analysis is introduced and applied in order to expand the initial design concept of the business model. Finally, both methods are aggregated and implications for the construction of a flexible business model are derived. Conclusion and outlook are presented in Sect. 4.

## 2 The CloudLogistic-Scenario

The basic concept of CloudLogistic bundles Less Than Truck Load-Shipments of different cooperating carriers via a centralized cooperation network - without any turnover at all. By bundling several Less Than Truck Load shipments synergy effects can be realized.

Thereby, CloudLogistic determines an assignment of shipments to a certain set of freight routes while decreasing the number of needed trucks, respectively the needed Full Truck Load capacity [6, p. 3].

Thereto, a dynamic relation-based traffic between several regions in Germany is established. Each of these freight routes builds relations between a source and a target area and is served by several trucks which are provided by the cooperation partners. Shipments are picked in the source area of a certain freight route and are transferred to the corresponding target area without any turnover at all (see Fig. 1).

Three essential key aspects of the CloudLogistic concept are:

- Direct-transportation without any turnover,
- Optional pick-up along the freight routes,
- Use of GPS-coordinates instead of postal-code-based boundaries.

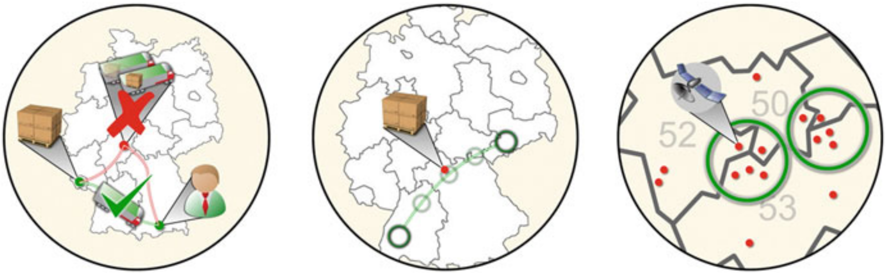


**Fig. 2** Point-to-point transportation without any hub-traffic (*left*), optional pick-up during the trip (*middle*), and distribution with geo-coordinates (*right*)

The central-controlled and optimized disposition of Less Than Truck Load shipments without any hub involvement makes it possible to deliver these shipments directly from point-to-point (see Fig. 2, left). Thereby hub costs can be saved and customer demands for example a turnover prohibition can be considered.

Spontaneous Less Than Truck Load shipments which can be pushed into the cooperation system by cooperation partners can be served by the optional pick-up. The optional pick-up assigns these orders to trucks which are already serving feasible freight routes with similar target areas. Furthermore, the system checks for free-capacity based on delivery time windows as well as for free freight hold (see Fig. 2, middle). With the optional pick-up cost-intensive empty runs can be prevented.

With the help of geo-coordinates the disposition is carried out with exact geographic positions instead of a postal code system for the source and target areas (see Fig. 2, right).

## 3 Business Model

The following sections present the applied scientific methods for the construction of a business model of a Less Than Truck Load freight cooperation. At first general requirements of such a cooperation concept are presented in Sect. 3.1. Based on these requirements the business model canvas (see Sect. 3.2) and a trend-based scenario technique are applied in order to develop a flexible business model (see Sect. 3.3). In a last step the aggregation of both methods is presented and implications for the construction of a business model are derived in Sect. 3.4.

### *3.1 Requirements for a Business Model of a Less Than Truck Load-Cooperation*

As business models base on the needs and requirements of its stakeholders, the design process of a business model must integrate all involved parties at an early stage

[7, p. 92]. To ensure the integration of all requirements for the development of an adequate business model two workshops were organized. Participants of both workshops consist of managers of German freight carriers and further experts of the freight transportation branch. Both workshops were designed equally in order to evaluate and expand the requirements of the first workshop in a second round. Afterwards we subdivide all identified requirements in functional and non-functional requirements. It is important to define functional and nonfunctional requirements when designing a business model in order to make sure that the system meets the business objectives [8, p. 152]. The functional requirements consist of the two groups Top-Level-Business-Processes and technical requirements concerning the collaboration platform for the centralized disposition. The non-functional requirements include cooperation-form, business activities and quality, fairness and incentives, finance clearing, price structure, source and target areas, load carriers as well as freight types. These identified functional and non-functional requirements form the basis for the business model development.

### *3.2 The Business Model Canvas Method*

The Business Model Canvas Method (BMC) (see Fig. 3)[1] from Osterwalder and Pigneur [9, p. 14] is a frequently used method in practice and beyond that constitutes a reference model in the area of business model research and development [10, p. 27]. An essential advantage of the BMC is its generic applicability for different use cases. The approach suits for the initial development phase of a business model as well as for an initial business model brainstorming phase [10, p. 190]. Therefore, we applied the BMC in order to develop an initial design concept for the business model in the context of CloudLogistic.

Referring to the work of Friedrichsmeier et al. [11] the identified and specified requirements of the small and medium sized logistic service providers (see Sect. 3.1) have been dedicated to the nine segments of the Business Model Canvas, which includes the core areas Customers, Offering, Infrastructure, as well as Finances.

This first design concept enables an initial overview about the functionality of the CloudLogistic cooperation within its key areas of customer-structure, range of services, technical and non-technical infrastructure, and degree of financial efficiency [11, p. 8].

However change requirements demand a permanent further development of the business model. In general business models of industry and trade exhibit a life cycle of 2–3 years. That is why especially the logistics sector needs flexible business models which can be adapted to changing requirements. Therefore, we expand the BMC method with a trend-based scenario analysis which generates a solid extended

[1] A high-definition version of the Business Model Canvas can be downloaded here: http://www.businessmodelgeneration.com/canvas published by Creative Commons License (Date of access 16 July 2012).

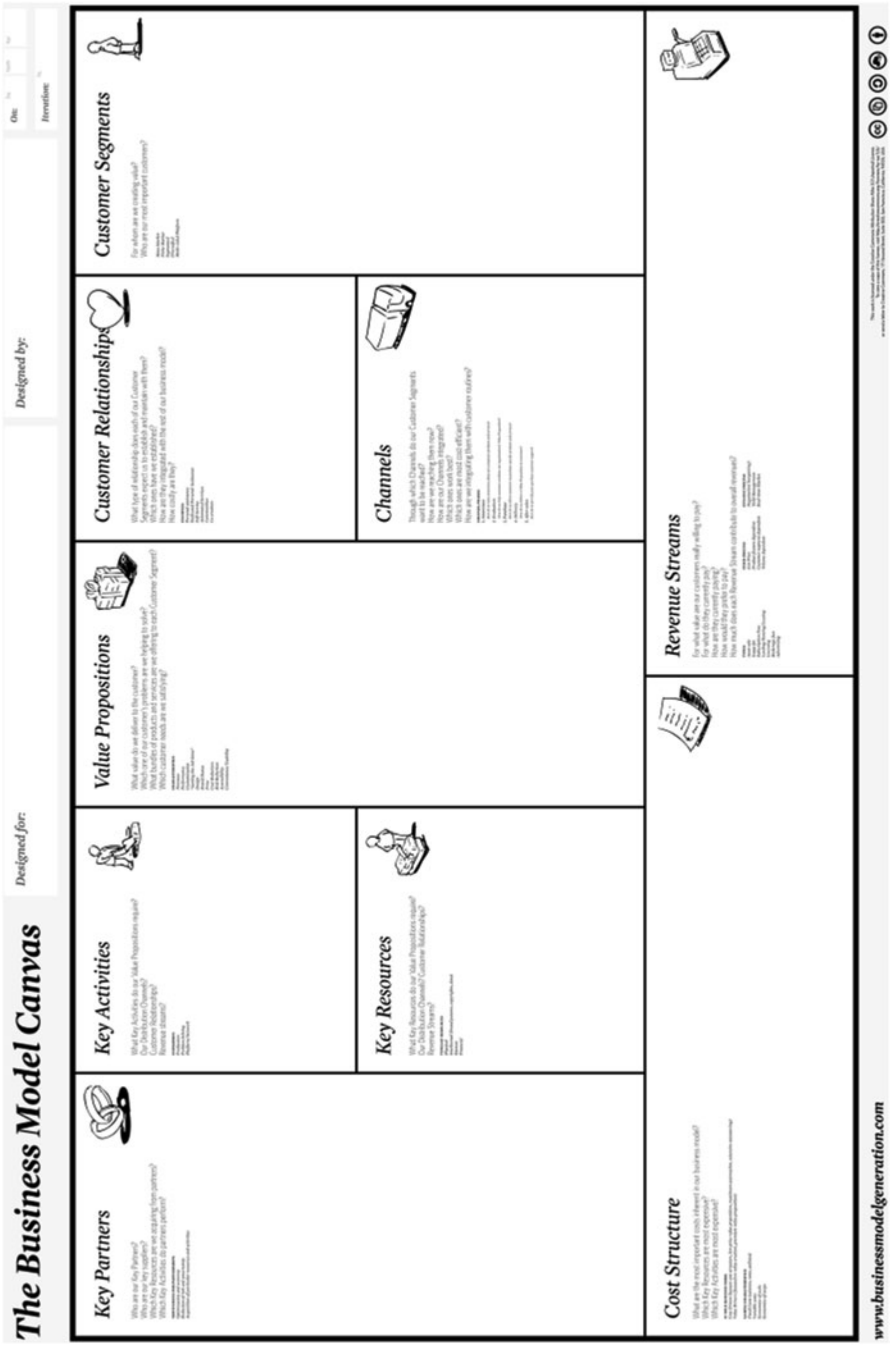


**Fig. 3** Business Model Canvas. (Source: http://www.businessmodelgeneration.com/canvas)

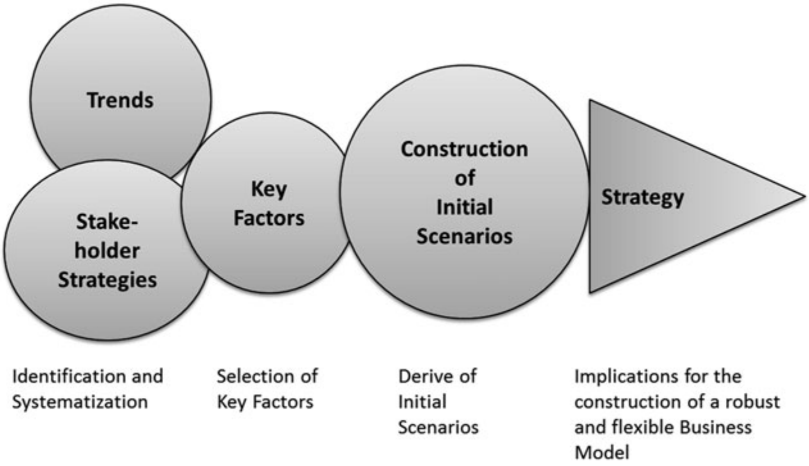


**Fig. 4** Trend-based scenario-technique according to Burmeister et al. [12, p. 48]

forecast to derive further implications for the next iteration phase in a business model development process.

### 3.3 *Scenario Analysis*

In today's volatile market conditions sustainable business models have to be flexible. A flexible business model helps organizations to gain the ability to adapt the model steadily to changing requirements and external changes. Building future scenarios helps to recognize economic, societal, and technological changes early and thereby to reduce costs by preventing hasty actions. With the application of a simplified trend-based scenario analysis based on Burmeister (see Fig. 4) we consider future perspectives for the construction of a robust business model of a Less Than Truck Load freight cooperation. This method fits well for our target group consisting of haulage operators and consultants of the transportation sector because it is based on current trends in the logistics sector which facilitates their access to the method.

Trends have a long-term effect and a huge impact on the future market conditions [13, p. 2] and consequently suit well for building initial scenarios. Thus, we identified current megatrends of logistics based on a recent study on trends and strategies in logistics of the German Logistics Association BVL.[2] Furthermore, we specified these trends in expert workshops[3] in order to derive influencing factors which are

[2] Cmp. BVL Study of present Trends in Logistics 2008.

[3] The trend-scenario bases on a workshop with experts from the freight transportation branch. Managers, external consultants as well as academics participated. Megatrends in logistics were discussed and built the foundation for the development of a CloudLogistic scenario.

examined on type (societal, environmental, and economic) and intensity (direct or indirect influence) for the presented scenario. Thus only the influencing factors with a direct impact on our scenario are taken into consideration for further analysis which builds the basis for the selection of key factors (see Sect. 3.3.2). Finally building on these key factors the forecast of a potential development path for the description of the CloudLogistic scenario is presented afterwards. To present a conclusive development path for this scenario up to the year of 2030 three different time horizons are highlighted in Sect. 3.3.3: **short-term-view**, **medium-term-view**, and a **long-term-view**. According to this analysis different implications for the construction of a business model for a Less Than Truck Load freight cooperation are derived.

### 3.3.1 Trends and Influencing Factors in Logistics

Over the past 10–15 years, against a background of increasing public and governmental concern for the environment, companies have come under mounting pressure to reduce the environmental impact of their logistics operations. Estimations show that freight transport accounts for roughly 8 % of energy-related CO2 emissions worldwide [14, p. 3–4]. This increasing environmental pollution has led to an increasing **environmental awareness** of the society. Consequently, companies are faced with an increasing public pressure and in addition with an increasing amount of tougher **environmental regulations** pushed by the government. All these factors provoke that environmental concerns and resource-protection become a megatrend in logistics.[4] Besides these environmental challenges other societal trends like the **demographic change** force small and medium sized logistic service providers to search for new solutions in order to realize operational efficiency (fully-utilized trucks, efficient shipment bundling etc.) in rural areas. Due to the demographic change younger people leave whole regions and move to bigger cities. This decline in population especially in these rural areas leads to new regional challenges due to a lack of sufficient order volumes. Besides these societal factors the trend of decreasing costs for logistics is interrupted. In contrast, it is predicted to increase in the future and therefore, haulage operators are faced with an increasing **economic pressure**.[5] This pressure is mainly based on increasing energy and fuel costs. The steeply increasing **oil price** in future years forces companies to improve their fuel efficiency as fuel costs represent a large part of total vehicle operating costs especially for the transportation sector [14, p. 229]. Also **prices for real estates** tend to increase which will lead to increasing fees for using hub-solutions to turnover shipments. Besides these societal concerns and the economic development logistics is faced with a demand on an increasing need for **safety requirements**[6]. Due to the last financial crisis in 2007 organizations are forced to create their supply chains flexible and more reactive to this kind of market disturbances in order to be able to sustain competitive.

[4] Cmp. Study of BVL (2008).
[5] Cmp. Study of BVL (2008).
[6] Cmp. Study of BVL (2008).

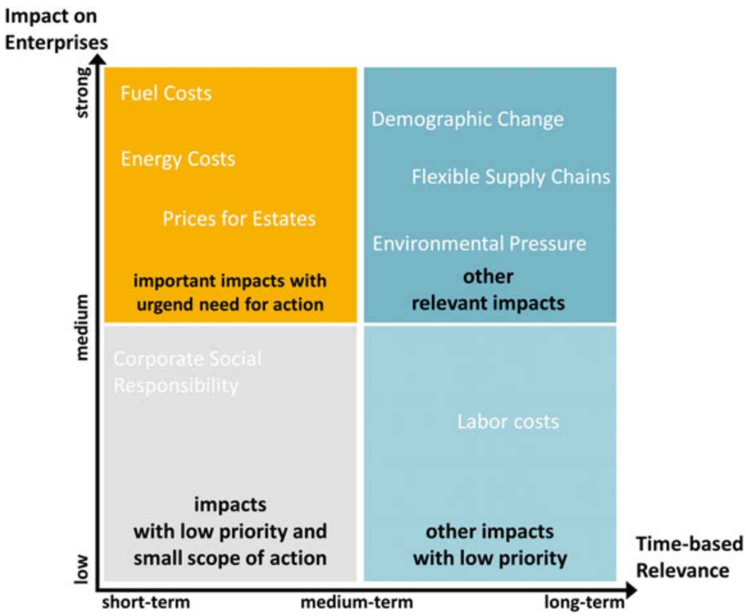


**Fig. 5** Impact analysis. (Source: Foresight Toolbox for Small and Medium Sized Enterprises 2008/2009)

In the following section we analyze all discussed influencing factors and trends on their impact on the CloudLogistic scenario. All factors which turned out to have a direct impact are considered as key factors which influence the development path of our scenario up to 2030.

### 3.3.2 Identification and Specification of Key Factors

In the following we assign the identified trends and influencing factors to an impact analysis diagram (see Fig. 5). Thereby the impact of a factor (strong, medium, low) on the organization and the time-based relevance (short-term medium-term and long-term) are reflected.

All factors which were assigned to the upper left quadrant represent key factors with an urgent need for action and thus, a direct impact on the CloudLogistic scenario. Factors which are located in the upper right corner are also of great importance but possibly not of an urgent need for action yet. The factors which were assigned to the quadrants at the bottom can be neglected for the further analysis as they are of low impact for organizations in the freight transportation market so far.

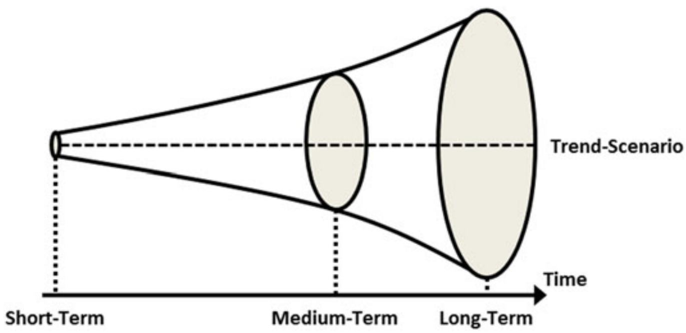


**Fig. 6** Scenario funnel

### 3.3.3 CloudLogistics – A Trend-scenario up to 2030

According to recent forecasts mentioning an increasing transport volume of about 55 % in the next years, new solutions in logistics are needed in order to deal with an increasing complexity while still ensuring higher flexibility of logistic processes. A cloud-based IT solution seems to be a promising way to cope with current demands with respect to the previous identified key factors (see upper quadrants of Fig. 5). In this section we present the CloudLogistic trend-scenario and three different time horizons (see Fig. 6) which range from the present up to the year of 2030 in order to present a conclusive development path [16, p. 82].

Similar to the term Cloud Computing we define CloudLogistic as the ability and opportunity of the logistic service providers to share unused resources by participating in a freight cooperation network. This is done by using its infrastructure and its resources to scale them locally while sharing their own infrastructure and resources with the network [5, p. 3]. Based on a centralized IT-based control panel which collects all incoming shipments, optimizes these shipments according to multi-criteria-optimization targets (minimum of used trucks, minimum of time spent for delivery etc.) and finally, assigns them to available resources in the cooperation network (trucks of cooperation partners), independent of who pushed the shipment into the system [17, p. 334]. In comparison to today's successful solutions of different freight cooperation concepts in terms of freight exchanges or general cargo networks, no similar concept for the Less Than Truck Load shipment sector exists yet. With the establishment of such an intelligent shipment system [5, 11] the economic efficiency of Less Than Truck Load shipment handling is addressed directly in a **short-term-view**. Especially the Less Than Truck Load shipment transport is very uneconomic because trucks are not fully utilized on the one hand, and on the other hand inefficient empty runs on a back trip are commonplace. By implementing the CloudLogistic cooperation solution logistic service provider can achieve a higher utilization rate of their trucks and furthermore route optimization saves fuel costs (see Fig. 6) and thus, realizes efficiency improvements.

Besides these economic motives technical innovations like the Internet of Things (IoT)[7] offer great perspectives to a cooperation network by connecting manufacturers, suppliers, final customers, and logistic service providers within a logistic network. IoT enables an improved information exchange and thus, a higher transparency of data, for all included stakeholders during the whole transformation process, is achieved which increases the flexibility of logistic systems [18, p. 1]. In a **short-term to medium-term-view** shipments can be followed by Track-and-Trace which helps customers to track their ordered shipments and thereby be able to estimate date and time of delivery. Hence, huge amounts of data are bundled (here: GPS-coordinates) in order to make estimations about delivery time, delivery delays, and faults. Within the CloudLogistic network it is possible to increase transparency for final customers by offering real-time-data for tracing orders and thereby realizing a continuous shipment tracking. A further step is to implement radio-frequency identification (RFID) technology for all Less Than Truck Load shipments and connect this technology to sensor technology. Thereby, it is possible to connect GPS-based positions of shipments to environmental-based data. So customers do not only know the exact location of their ordered shipments, but are also able to make conclusions about conditions of ordered goods by monitoring information about temperature, humidity, and shock data during transportation. Thus, the combination of RFID und sensor technology offers a great opportunity for improving the efficiency of supply chains [19, p. 2794].

In a **medium-term-view** a strategic step to realize additional optimization potential is to alter the static existing freight route system to a partially dynamic freight route system which removes routes from the system and adds adapted routes according to changing order volumes and historical demand data. This partially dynamic system would help to reduce initial consequences due to demographical change. In a **medium to long-term view** daily freight route adaptions based on real data are the final step to exploit further optimization potential. That means all freight routes are proven on a daily basis and are adapted to the order volume and then all shipments are assigned to the resources within cooperation network. That means regions with a weak demand history are changed by adapting corresponding source and target areas with higher demand-rates.

In a **long-term-view** it can be assumed that environmental concerns hold on until 2030. Environmental regulations pushed by the government force organizations to assess their environmental performance in the future. Therefore, derived values like the carbon footprint can be integrated into the multi-criteria optimization target, so that the CloudLogistic scenario guarantees an equally calculated carbon footprint value for every cooperation member and helps to increase the comparability among

[7] The idea of Internet of things (IoT) relies on a vision of Kevin Ashton who was a co-founder and chief-officer of the auto-ID-center of the MIT in the late 1990s. He thought about a growing conflation of physical things and the digital world of the internet where things can act autonomously in a data-linked environment [20, p. 13].

all partners' environmental performance. Consequently environmentally-friendly cooperation members become prioritized over partners with poorer carbon footprint values.

Apart from these described scenarios in the following we want to present a futuristic scenario (**long-term view**). In this scenario trucks act as own entities on the market which means every truck acts as its own carrier which spreads risk, increases flexibility and still ensures the quality of logistics services because autonomous, decentralized logistics entities are loosely integrated and coordinated by a flexible overall system. Similar to the term "Platform as a Service" (PaaS) introduced by the Cloud Computing community not only a software implementation is provided but also a platform to integrate logistic service providers which actually executes the demanded services. This means that a cloud service provider acting on this level might become what is often referred to as a fourth-party logistics provider [21, p. 308]. With the realization of such a scenario the optimization potential of shipment assignment would be nearly maximized.

However, these autonomous cloud solutions include potential drawbacks. Besides technical challenges like connectivity problems depending on factors of driver positions without sufficient bandwidth or data security aspects, other practical hurdles have to be cleared, e. g. daily changing freight routes limits the driver's location-based experience and knowledge. Furthermore, with steadily changing routes no key customer segment exists anymore. The implementation of such a futuristic scenario will take several years as technical progress is necessary to overcome major barriers. Nonetheless a market survey by Fraunhofer IML comes to the conclusion that 64 % of 70 logistics executives interviewed can imagine employing cloud computing solutions already today [21, p. 309].

### *3.4 Aggregation of Business Model Canvas and Scenario Analysis*

In this section we merge the results of the BMC with future impacts drawn from the trend-based scenario analysis. Thus, the overall objective of the paper is to combine both scientific methods and finally, to expand a first design concept of a business model.

All following implications are drawn from the development path of the presented CloudLogistic scenario and have in common that they strive for efficiency-improvements: on the one hand resource efficiency is a major objective and on the other hand operational efficiency represents a major ambition.

Referring to the derived environmental concerns major implications for the development of a business model focus on fairness and incentive models. In a long-term-view environmental targets affect fairness models as the measurement of environmental performance of cooperation members correlates positively to the number of assigned shipments. Furthermore, the achievement of an adequate environmental performance can indicate an incentive for cooperation members to improve their environmental performance and do not create insurmountable hurdles. Therefore, driver trainings can be introduced as additional "green incentives" in order to promote efficient driving which can affect emission targets positively and thereby can decrease a firm's carbon footprint. Besides green initiatives other implications referring to the operational efficiency are part of the analysis above. The term CloudLogistic as well as an increasing influence by the Internet of Things turned out to have some major implications on the development of a business model for a Less Than Truck Load freight cooperation. Increasing flexibility boosted by these technical innovations comes along with a higher relevance and demand of data security and insurance issues. With an increasing complexity due to an integration of more and more entities along a supply chain (suppliers, customers, transportation, IT-systems etc.) it becomes imperative for logistics to plan, coordinate, and control the material- and information flows and beyond that to ensure confidentiality of customer data and data security. Furthermore, employees need to be trained on issues like data security of customer data in order to prevent careless handling of confident data. In addition the use of common mobile devices especially in logistics (for example RFID reading devices, track-and-trace devices etc.) has to be adapted to new security requirements. Therefore, correspondent data-security-concepts have to be developed to integrate these mobile devices into the cloud. Referring to the futuristic scenario of the CloudLogistic scenario (see Sect. 3.3.3) new insurance concepts have to be implemented into the business model. Questions as who is responsible for any kind of faults (quality defects, delivery delays etc.) at what stage of the supply chain have to be covered in a future business model.

In summary, it turned out to be very important to deal with chances and risks of upcoming trends in order to develop a robust and flexible business model for an uncertain future.

## 4 Conlusion and Outlook

CloudLogistic focuses its research on the development of an innovative logistics concept for the Less Than Truck Load freight segment in order to strengthen the market position of small and medium sized logistic service providers. For the development of a flexible business model the Business Model Canvas (BMC) of Osterwalder and Pigneur is applied to build an initial design concept. This method has been expanded by a trend-based scenario-analysis. Implications for theory are to expand the business model development methods with a structured strategic foresight process by the integration of a trend-based scenario-analysis.

With the help of the scenario technique we were able to assess chances and risks of potential trends in logistics and to derive strategic implications for the corresponding business model. Especially fairness and incentive models are affected by the environmental pressure in future years. Furthermore, data security and insurance issues are implications resulting from the technical innovations due to the Internet of Things which have to be covered by a futuristic business model for a freight cooperation.

Besides the identified implications on theory in the business model development also implications for the practice can be derived. Organizations have to be sensitized that an initial design concept of a business model cannot sustain in the future without any changes at all. A continuous trend monitoring is required and helps organizations to expose and assess present trends and thereby to identify future needs which have to be covered by their business model. That means, beside the construction of an initial business model design concept a structured business model change process is also needed in order to maintain an ongoing adaptability of their business models.

In further research works all identified implications have to be evaluated by an execution of a classical scenario analysis because here only a simplified version of the trend-based scenario analysis has been applied. A classical scenario analysis analyzes the interaction of all identified key factors which is beyond the scope of this paper. Within this analysis we only discussed the development path without considering optimistic and pessimistic developments due to potential external disturbances or crises which would also been done in an extensive scenario analysis. Nevertheless, due to a general positive correlation between strategic planning and a company's success the application of the BMC combined with a scenario technique turned out to be a valid method to derive strategic implications to be able to expand the first design concept with future implications for constructing a flexible business model for a Less Than Truck Load freight cooperation.

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# Scientific Performance Indicators – Empirical Results from Collaborative Research Centers and Clusters of Excellence in Germany

**Florian Welter, Stefan Schröder, Ingo Leisten, Anja Richert and Sabina Jeschke**

**Abstract** Collaborative research centers and clusters of excellence constitute public funded programs aspiring to advance research in interdisciplinary forms of collaboration throughout Germany. Due to emerging funding volumes and increasing expectations in results, concepts for performance measurement and management gain in importance. Results of an empirical study among all actively funded collaborative research centers and clusters of excellence make obvious that key performance indicators – such as the quota of publications or the number of international visiting researchers – are central. Nevertheless, holistic methods and concepts of performance measurement seem still not to be widespread among respective speakers and chief executive officers.

**Keywords** Scientific Performance · Performance Measurement · Key Performance Indicators · Collaborative Research Centers · Clusters of Excellence · Empirical Study

## 1 Introduction

As stated by the German Ministry of Science and Technology (BMBF) in 2008, the aim of the government is to promote the country in order to become one of the most competitive global locations in terms of science, research and innovation (cf. [1, p. 5]). This is to be achieved by further exhausting its potential of creativity and innovative capability, especially with regard to research and development activities in interdisciplinary forms of collaboration. Against this background, public funding for collaborative research centers (CRC) was expanded in 1999 and public funding for clusters of excellence (CoE) was initiated by the German government and the federal states in 2006. Regarding the size of the consortia, the funding volume and the degree of interdisciplinarity, the two programs break with other research structures and constitute innovative instruments for the promotion of collaborative research.

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Hence framework conditions and aims of both programs will be described in the first sections of this paper.

Adequate concepts for performance measurement and performance management of interdisciplinary collaborative research depict new challenges for promoters and science managers in the research environment of the twenty-first century (cf. [2], p. 34). This can be explained by an augmenting degree of complexity concerning structures and behavior of interdisciplinary forms of collaborative research demanding new forms of organization and management (cf. [3, 4]). In order to measure and manage the performance, the definition and collection of scientific key performance indicators (KPIs) depicts an approach that can be used as a base for steering decisions in interdisciplinary scientific collaborations. This includes indicators to measure e. g. the quality of scientific exchange, output and sharing of information in contrast to e. g. classical monetary indicators of profit-organizations. Whereas former and contemporary scientific publications focus on university performance in terms of a single organization (cf. [5–7]), research concerning performance on an inter-organizational level of scientific cooperation constitutes a new field of research what will be outlined in a following section of the paper (cf. [8–10]).

The initial description of CRC and CoE as objects of research as well as the characterization of contemporary challenges in performance measurement and management lead to the super-ordinated research question of the paper: Which KPIs are suitable to measure the performance of CRC and CoE? After presenting the design of an empirical study, the paper will provide results that base on a semi-standardized survey which was addressed to the speakers and chief executing officers of all active German CRC and CoE giving insights in the ranking and comparison of KPIs. The study provides answers about the frequency and the methodology used concerning the process of scientific performance measurement. Moreover, it reflects the impact of the programs CRC and CoE on the promotion of the research location Germany.

In the final sections of the paper the framework of the empirical study is discussed. This is followed by concluding remarks concerning the main results of the study. The latter also gives evidence about a further need for research in the topic of performance measurement and management in the context of CRC and CoE.

## 2 Forms of Public Funded Scientific Collaboration in Germany

Speaking of different forms of public funded scientific collaboration in Germany, especially funding instruments of the German Research Foundation (DFG) like groups of researchers, graduate schools, CRC and CoE are characteristic. Regarding e. g. structural aspects, the degree of interdisciplinarity and overall (strategic) targets of CRC and CoE, a comparison appears to be reasonable. Here studies and literature provided by the DFG as well as the German Council of Science and Humanities (WR) are used in particular.

For both forms the main funding volume is provided by the BMBF and respective ministries of the sixteen German federal states. The average number of employees of the actually 242 promoted CRC depict forty-one employees with an average public funding volume of 1.67 million € per year and CRC (cf. [11, 12, p. 6]). Considering the four major groups of scientific disciplines (arts and social sciences; life sciences; natural sciences; engineering) which are classified by the DFG, it can be stated that life sciences represent the strongest group among CRC with a share of over 40 % of all funded CRC. Approximately 25 % of all funded CRC is located in natural sciences, about 20 % falls to engineering and about 10 % belongs to the group of arts and social sciences (cf. [12, p. 6]).

In comparison to that, the average annual funding volume in CoE amounts about 6.5 million € per year and CoE with an average number of forty-one employees (cf. [11–13, p. 21]). Nearly 17 % of the funding volume is spent for CoE in arts and social sciences, about 31 % for CoE with the focus on life sciences, about 25 % for CoE with an emphasis on natural sciences and nearly 27 % to CoE focusing on engineering (cf. [14]).

Considering structural and organizational aspects, e. g. management boards, speakers as well as chief executive officers and coordinators are prevailing in CRC and CoE (cf. [12, 15]). Both forms of collaborative research are characterized by a relatively heterogeneous composition of their actors which expresses itself e. g. in diversity of disciplines and the integration of several scientific institutes and affiliated partners – partly industrial partners and/or non-university research institutes – in a consortium. Due to strategic aims of the promoters, such as strengthening the existing structures of individual scientific institutions, promoting young scientists or enlarging the international reputation of Germany as a research location, interdisciplinary teams of scientists increasingly collaborate in common research topics (cf. [11, 15]).

The overall aim of CRC is to support excellent research within the scientific network and to facilitate the universities' focus through a long-term funding lasting up to 12 years (cf. [16, p. 1]). From 1968 till 1999 the composition of CRC was limited to one university which simultaneously occurred as applicant for public funding. From 1999 CRC program variants induced a diversified structure (cf. [17]). In this way so called CRC/Transregio, which have to demonstrate the participation of several leading universities (normally up to three universities) as a basis for their research work, can be promoted as well. Thereby the former local profile was changed (cf. [17]) so that not only scientists have to be integrated in a CRC that work at the same location but also scientists from different research locations across Germany.

CoE constitute a funding program in the context of the German excellence initiative. The latter has been initiated by the BMBF as well as the German federal states in 2005 in order to strengthen university structures, promoting Germany as a location for excellent science. In the course of the first funding period of the excellence initiative, 37 CoE were initiated in the years 2006 and 2007 for at least 5 years. The provision of an excellent research performance within the respective scientific fields represents a superior funding requirement (cf. [18, p. 2 f.]). Besides the intention to create and exploit synergies at one university, the willingness for an interdisciplinary cooperation with other universities, institutes and (regional and international) partners from industry is desired. To establish structural sustainability of CoE, cooperative relations with the private sector are of great importance to reduce

**Table 1** Central aspects of comparing CRC with CoE

| Similarities of CRC and CoE | Differences between CRC and CoE |
|---|---|
| Aiming at improving the structural development of universities | First initiation in Germany (CRC: 1968 vs. CoE: 2006) |
| Aiming at promoting young scientists and women in science | Average funding volume: 1.67 millions of € per year and CRC vs. 6.5 millions of € per year and CoE |
| Cooperation with (partly non-university; international) research institutes | Duration of respective funding periods (CRC: 4 years vs. CoE: 5 years) |
| Objective to transfer scientific results (e. g. into practice) | Stronger focus on basic research than on applied research in CRC in comparison to CoE |
| Aiming at an increasing international visibility and reputation of the research location Germany | Local profile of leading partners in classical CRC and CoE vs. leading partners from different regions in CRC/Transregio |
| Central organizational structures (e. g. speakers and chief executive officers) | |

the dependence on public funding in the long-term (cf. [13, 51 f.]). The thematic coherence of the scientific program depicts another funding requirement that has to be internationally visible and relevant for social and economic interests. Moreover, the internal promotion of young researchers as well as gender equality are expected (cf. [18, p. 2 f; cf. Table 1]).

An ongoing public funding of CRC and CoE is in accordance with the overall strategy of BMBF and DFG to overcome the pillarization of single disciplines enabling cross-sectional innovations (cf. [19]). Due to the augmenting complexity of these new forms of cross-sectional collaboration, performance measurement aspires to contribute to steering and regulation of CRC and CoE what will be outlined in the following sections.

## 3 About a Changing Understanding of Performance Measurement

The current term performance is ambiguously defined within literature. On the one hand performance is defined as the consequence of efficient and effective actions on all service and decision-making levels of an organization in the light of satisfying plural interests concerning multidimensional objectives such as finances, quality or processes (cf. [20, p. 33]). On the other hand performance stands for the quality of benefits for the stakeholders of an organization (cf. [21, p. 49; 22, p. 10]). For Neely [23] performance measurement embodies a process of quantifying efficiency and effectiveness of an action. With help of performance measurement, organizational objectives shall be improved and the cross-hierarchical communication and cooperation shall be promoted (cf. [24, p. 239]). Performance measurement has its roots in business administration – especially in the sub-areas: financial management, human resources and controlling. In this context it is directly linked to the phases of management: planning, steering and controlling and embodies the process of defining goals as well as setting up a feedback process for an organization in the sense of a cybernetic loop (cf. [25, p. 21]).

It is notable that the understanding of performance measurement and respective KPIs has changed in theory and practice since the 1990 s. In the conventional sense, KPIs represent quantitative data compressing a complex reality (cf. [26, 15; cf. 27, p. 5]). As proponents of a changing understanding of performance measurement and associated indicators, Eccles [28] as well as Kaplan/Norton [29] point to the need to measure KPIs which go beyond financial aspects and which possess a multidimensional character (cf. [30]). To provide information, e. g. about output or processes of an organization, KPIs thus play a decisive role for persons in leading management positions. To develop and to collect a set of KPIs, different methods can be used (cf. [31, p. 167]). Diverse dimensions have to be considered such as the past- or future-orientation of indicators, the organization-internal or -external use of indicators, and the nominal or interval scaling of indicators. Overall, KPIs are ideally allowing a certain indicator-flexibility and dynamic of change (cf. [25, p. 23]).

With the ascent of the New Public Management in the 1980s which advanced the transfer of management methods and principles from the private sector to public administrations and institutions, further fields of application emerged for performance measurement such as research facilities, research associations, CRC or CoE (cf. [32, p. 37 ff.]). Concerning the implementation of performance measurement in CRC or CoE, e. g. the challenge can be described by supporting the realization of defined objectives, providing information about ongoing processes and decisions as well as supplying a base for decision-making for the management and integration of interdisciplinary research partners (cf. [9]).

Whereas performance measurement in a profit-oriented organization is targeted to profit maximization, performance measurement in the context of CRC and CoE primarily focus on the measurement of efficiency in interdisciplinary collaborations. Hence, the research output like (interdisciplinary) publications, awards, products, new projects and the quality of processes e. g. concerning cooperation, communication and research work have to be measured. Performance measurement within CRC and CoE has to be guided by the visions and objectives determined in the application of funding. In order to achieve the defined objectives as well as to initiate a continued improvement process among all stakeholders, the results of performance measurement are used to draw up recommendations for steering and regulating interdisciplinary forms of collaboration. At this point it has to be emphasized that the importance of financial KPIs is relativized. Finances represent the base of a continual improvement process and not the overall target in the context of a non-profit scientific organization. Innovation and learning processes – including associated KPIs – are focused instead in scientific collaborations (cf. [33]).

The need for concepts to measure, steer and regulate the examined forms of scientific collaboration is expressed by organizations that are responsible for public funding such as the DFG and the WR (cf. [15, p. 44 f.; 13, p. 7]). Thus, the study aims at providing more empirical evidence about application and diffusion of KPIs as well as forms of performance measurement in CRC and CoE.

# 4 Design of the Empirical Study

To gain more evidence about the application of performance measurement approaches in CRC and CoE an empirical study was executed throughout Germany in 2010/2011. The study also aspired to receive an evaluation of scientific performance indicators by representatives of CRC and CoE and insights about the impact of CRC and CoE on the promotion of the research location Germany. For the design of the study an online-survey was carried out using a semi-standardized questionnaire which followed Dillman's [34] total design method. Not only questions with interval scaled variables but also questions with open answers were constructed to facilitate comments in form of free text. The range of the interval scaled variables covered five possible answers enabling neutral answers, too, plus the optional answer 'no indication'. The group of speakers and chief executive officers of all actively funded CRC and CoE ($n = 278$) was selected as the target group (except two CoE at RWTH Aachen University in which the authors of the study are involved as members) because – due to their high responsibility as science managers – it is the most capable group for statements concerning adequate KPIs and methods of performance measurement.

The selection of respective items of the questionnaire based on the following considerations: The success of a CRC or CoE is fundamentally determined by the attainment of objectives formulated in the respective funding agreement. Thus, the overall objectives of CRC and CoE (among other things: strengthening the science location, improving the international competitiveness or expanding excellent peaks in the science sector) as well as possible forms for measuring the attainment of objectives were requested in the questionnaire. The overall objectives of both forms of scientific collaboration were derived from the funding criteria of the DFG and the WR (cf. [12, 14]). These were:

(a) research quality,
(b) originality and coherence of the scientific program,
(c) interdisciplinary collaboration,
(d) influence on the field of research in future,
(e) options for transferability into practice,
(f) quality of scientists and their further options for development,
(g) integration of local research capacities,
(h) structural development of the university,
(i) international visibility.

# 5 Results

## *5.1 Selected Results Concerning Participants and Response Quota*

A total of about 40 % of all addressed speakers and chief executive officers ($n = 278$) participated or at least started with the survey whereas the response quota was about

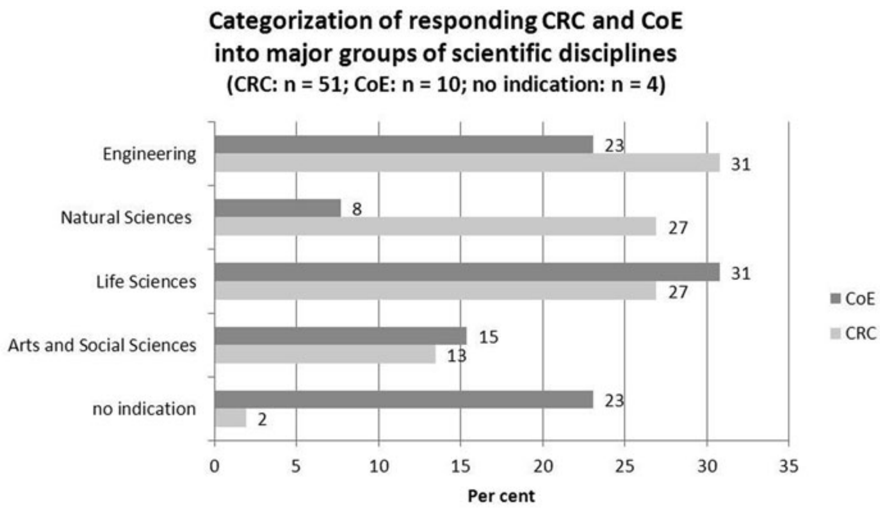


**Fig. 1** Categorization of responding CRC and CoE into major groups of scientific disciplines

23 % (finished surveys: $n = 65$). The majority of those respondents that did not complete the survey cancelled the survey after the introduction and the general questions. The entire number of sixty-five exploitable surveys allowed analyses by means of descriptive statistics.

In detail about 21 % ($n = 52$) of all active CRC and about 37 % ($n = 13$) of all active CoE – except the two CoE of RWTH Aachen University in which the authors are involved – took part in the survey. With reference to the four major groups of scientific disciplines (arts and social sciences; life sciences; natural sciences; engineering) it can be stated that representatives from all groups answered the survey (cf. Fig. 1). Referring to the latter, 23 % of the responding CoE answered with 'no indication' what can be explained by a higher degree of interdisciplinarity in CoE in comparison to CRC.

Structural differences in terms of varying numbers of employees became obvious during the data analyses, too. Whereas all participating CoE indicated to have more than one-hundred employees, the numbers are varying among CRC. In detail about 39 % of the participating CRC have ten to fifty employees about 52 % have fifty to one-hundred employees and just about 6 % indicated to have more than one-hundred employees.

## *5.2 Selected Results Concerning the Importance of Performance Measurement and KPIs in the Context of CRC and CoE*

The interval scaling of the closed questions (in style of the German school mark system) allowed data analyses e. g. considering arithmetic averages ($\bar{\chi}$) and corresponding standard deviations ($\sigma$) to analyze the dispersion of answers. Open

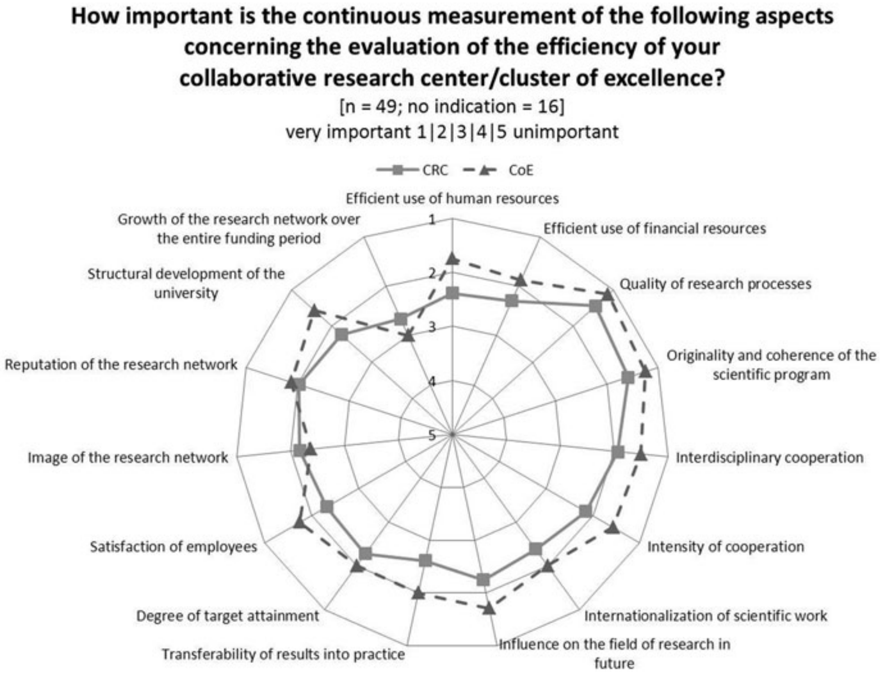


**Fig. 2** Importance of continuous performance measurement

questions enabled the addressed speakers and chief executing officers to add suggestions or criticism.

In the following network diagrams results are represented as arithmetic averages to enable interpretations according to the German school mark system, including e. g. 'indifferent answers'. The results are symbolized by squares for CRC and by triangles for CoE (cf. Fig. 2).

With reference to the fulfillment of external funding criteria – formulated by the DFG and the WR – the speakers and chief executive officers were asked to respond to the question: How important is the continuous measurement of the following aspects concerning the evaluation of the efficiency of your CRC/CoE? (cf. Fig. 2). Answers could be given by an interval scale ranging from 1 = very important, 2 = important, 3 = neutral, 4 = less important to 5 = unimportant plus the optional answer 'no indication'.

Regarding the answers of the CRC in Fig. 2, the top three items concerning the importance of a continuous performance measurement depict: quality of research processes ($\bar{\chi} = 1.44$; $\sigma = 0.73$), originality and coherence of the scientific program ($\bar{\chi} = 1.59$; $\sigma = 0.81$) and interdisciplinary cooperation ($\bar{\chi} = 1.93$; $\sigma = 0.85$). The growth of the research network over the entire funding period ($\bar{\chi} = 2.66$; $\sigma = 0.82$) constitutes the least important item concerning the answers of the CRC. Here one can assume that the expansion of a public funded CRC is rather associated with a phase of structural sustainability, e. g. including private promoters, than during the phase of public funding.

With reference to the three most important items concerning a continuous performance measurement in CoE, the same ranking as in the CRC can be described: quality of research processes ($\bar{\chi} = 1.13$; $\sigma = 0.35$), originality and coherence of the scientific program ($\bar{\chi} = 1.25$; $\sigma = 0.46$) and interdisciplinary cooperation ($\bar{\chi} = 1.50$; $\sigma = 0.53$). The answers among the speakers and chief executive officers just vary a few what can be underlined by low $\sigma$-values. Analyzing the least important item in the eyes of CoE representatives – and parallel to the results of the CRC – the growth of the research network over the entire funding period ($\bar{\chi} = 3.00$; $\sigma = 1.10$) is named. The dispersion of the corresponding answers is relatively high what can be due to a more sustainable strategic management of collaborative research in CoE than in CRC.

In summary, 13 from 15 items concerning Fig. 2 are evaluated as being important or very important among CoE representatives whereas the items were evaluated slightly worse among CRC representatives. Overall, one can assume that the importance of performance measurement seems to be more important among CoE representatives than among CRC representatives. The quality of research processes constitutes the most essential item for both forms of scientific collaboration. This emphasizes that e. g. an optimization of interdisciplinary research processes in terms of effectiveness and efficiency constitutes a central task within CRC and CoE.

In a following question the speakers and chief executive officers were asked: How do you evaluate the following indicators concerning an evaluation of the performance of your CRC/CoE? In contrast to the previous questions, answers could be given by an interval scale ranging from 1 = very appropriate, 2 = appropriate, 3 = neutral, 4 = less appropriate to 5 = inappropriate and the optional answer 'no indication' (cf. Fig. 3).

The top three performance indicators of the CRC are: quota of publications ($\bar{\chi} = 1.66$; $\sigma = 0.82$), citation index ($\bar{\chi} = 2.15$; $\sigma = 1.04$) and quota of successful PhD graduations ($\bar{\chi} = 2.18$; $\sigma = 0.87$). Searching for the least appropriate indicator among the CRC representatives, the number of patent applications ($\bar{\chi} = 3.44$; $\sigma = 1.33$) can be mentioned what is not really astonishing due to the fact that CRC classically focus more on basic research than on applied research. As a reason for the relatively high $\sigma$-value, a changing understanding of the CRC research alignment can be supposed, e. g. in terms of a growing share of practice-oriented research questions in CRC. Furthermore, the $\sigma$-value can be explained by different scientific alignments of CRC. Hence, patents are more probable in engineering than in arts and social sciences.

The top three performance indicators of CoE constitute: number of international visiting researchers ($\bar{\chi} = 1.75$; $\sigma = 0.71$), quota of publications ($\bar{\chi} = 1.86$; $\sigma = 0.69$) and number of awards ($\bar{\chi} = 2.00$; $\sigma = 0.58$). The least appropriate performance indicator for CoE depicts the number of patent applications ($\bar{\chi} = 3.42$; $\sigma = 1.29$), although the level of disagreement among the participants is relatively high. Like in CRC, this can be explained by different scientific alignments in CoE.

As a conclusion of Fig. 3 one can state that the performance indicator: quota of publications is evaluated in average as the most important indicator for scientific performance in CRC and CoE. The indicator does not only receive the best evaluations

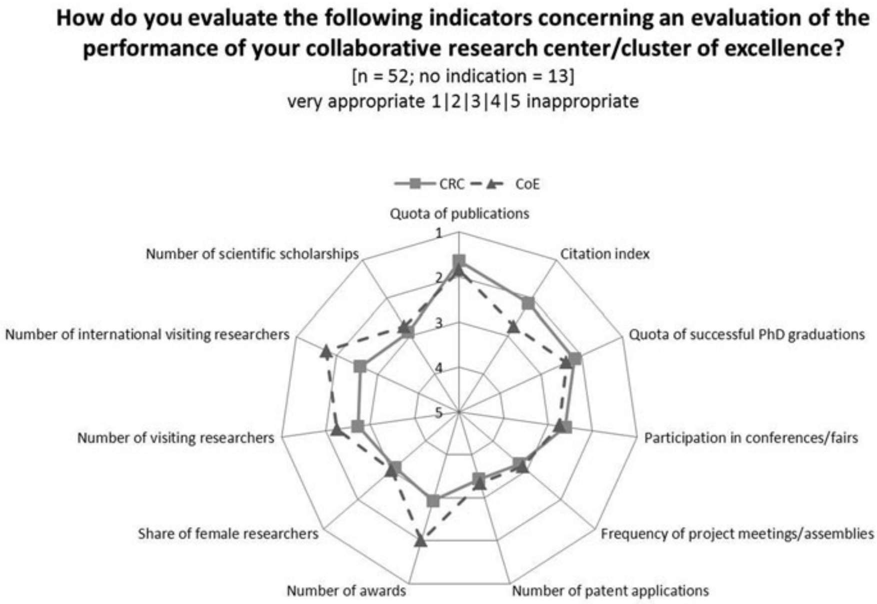


Fig. 3 Evaluation of performance indicators

in average, but also a high level of agreement by all respondents – elucidated by the low $\sigma$-value. Considering the other top performance indicators of CRC and CoE, it appears as if CRC emphasized more classical scientific performance indicators such as citations in comparison to CoE which e. g. highlighted the number of awards.

All respondents were asked to add further performance indicators or comments from their point of view in a corresponding open question section of Fig. 3. The performance indicators/comments are subjective, have not been evaluated by other participants and were divided into six categories (cf. Table 2).

The emphasized performance indicators/comments underlined a holistic, multi-dimensional understanding of performance measurement by the respondents. Hence, qualitative aspects like personal reputation of the involved scientists or benefit of scientific results for practice, as well as quantitative aspects such as return on investment with regard to funding or number of cooperations with industrial partners were named.

## 5.3 *Selected Results Concerning the Impact of CRC and CoE on the Promotion of the Research Location Germany*

The impact of CRC and CoE on the promotion of the research location Germany was evaluated in a subsequent question. The participants of the survey could answer by

**Table 2** Categorized additional performance indicators and comments

| Category | Performance indicators/comments |
|---|---|
| *Publications/theses* | Common (interdisciplinary) publications of sub-projects |
| | quality of publications |
| | Comparison of scientific results with the respective state-of-the-art |
| | Share of finished PhD examinations graded with 'summa cum laude' |
| | Number of supervised master theses |
| *Scientists* | Personal reputation of the involved scientists |
| | Number of scientists (and especially female scientists) appointed to professorships |
| *University structures* | Structural development of the university |
| *Internationalization, networking and public relations* | Internationalization of scientific concepts |
| | Organization of (international) conferences |
| | Global networking with other subject-specific research networks |
| | Public relations (e. g. events and projects) |
| *Benefits of results for practice and exploitation* | Benefit of scientific results for practice |
| | Exploitation of scientific results in science/economy/society |
| | Number of cooperations with industrial partners |
| | Number of transfer projects (and application of results in economy) |
| *Finances and funding* | Number of sub-projects receiving additional funding by programs of the European Union |
| | Return on investment with regard to funding |
| | Amount of additionally acquired project funding by involved scientists |

an interval scale ranging from 1 = very applicable, 2 = applicable, 3 = neutral, 4 = less applicable to 5 = not applicable plus the optional answer 'no indication' (cf. Fig. 4).

Regarding the top three answers given by the speakers and chief executive officers of CRC, the respondents highlighted the relatively high added value of the funding program CRC for the German science system ($\bar{\chi} = 1.37$; $\sigma = 0.58$). This item is followed by the statement that the CRC promoted the funding of young scientists in Germany ($\bar{\chi} = 1.50$; $\sigma = 0.77$). In addition to that, innovative research concepts were realized ($\bar{\chi} = 1.63$; $\sigma = 0.72$) with help of the program CRC. Concerning the least applicable impact of the funding program CRC, the intensified cooperation with economy ($\bar{\chi} = 3.38$; $\sigma = 1.06$) was indicated what e. g. can be explained by a relatively strong basic research alignment of CRC and a weak involvement of industrial partners.

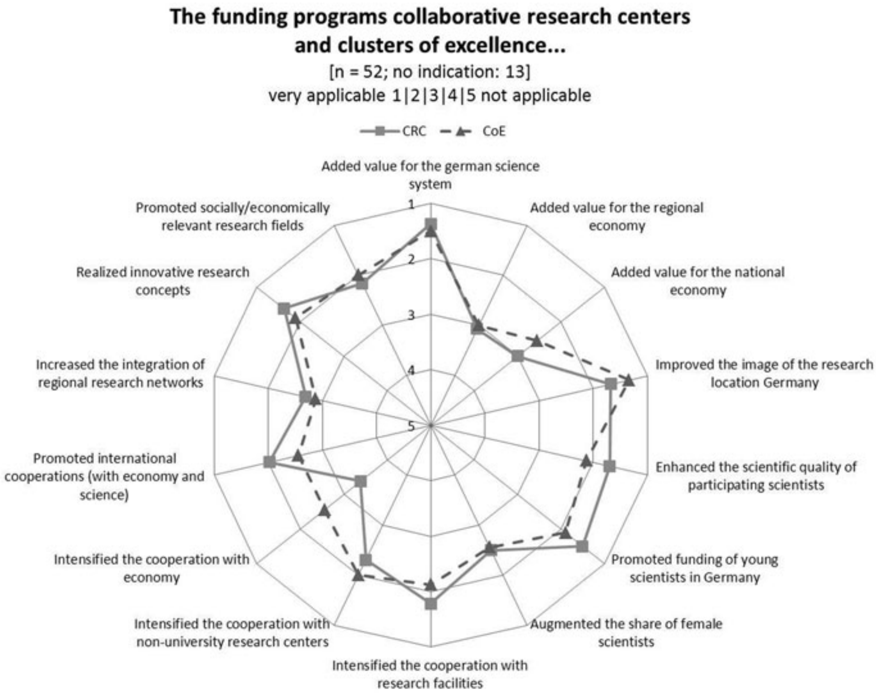


**Fig. 4** Impact of CRC and CoE on the promotion of the research location Germany

With reference to the CoE, the participants associated the highest impact with the image improvement of the research location Germany ($\bar{\chi} = 1.33$; $\sigma = 0.50$). This is followed by the added value for the German science system ($\bar{\chi} = 1.50$; $\sigma = 0.53$) as well as the statement that CoE promoted the funding of young scientists in Germany ($\bar{\chi} = 1.89$; $\sigma = 1.05$). Analyzing the least applicable aspect concerning the impact of the CoE, the added value for the regional economy ($\bar{\chi} = 3.00$; $\sigma = 0.71$) was indicated what could be traced back to the fact that CoE constitute a relatively new funding program, initiated in 2006.

## 5.4 *Selected Results Concerning Frequency and Methodology Used in the Context of Performance Measurement in CRC and CoE*

Indicating the frequency and methodology used in the context of performance measurement in CRC and CoE was the focus of Fig. 5. Analyzing the CRC answers, 32 % of the respondents stated to collect the performance indicators on a yearly basis, 21 % on a six-monthly basis, 20 % sporadically, 17 % on a quaterly basis and 11 %

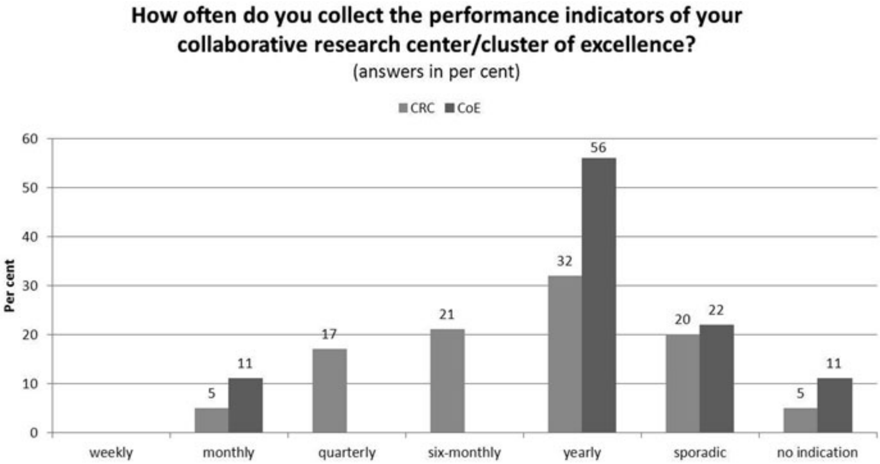


**Fig. 5** Frequency of collecting performance indicators in CRC and CoE

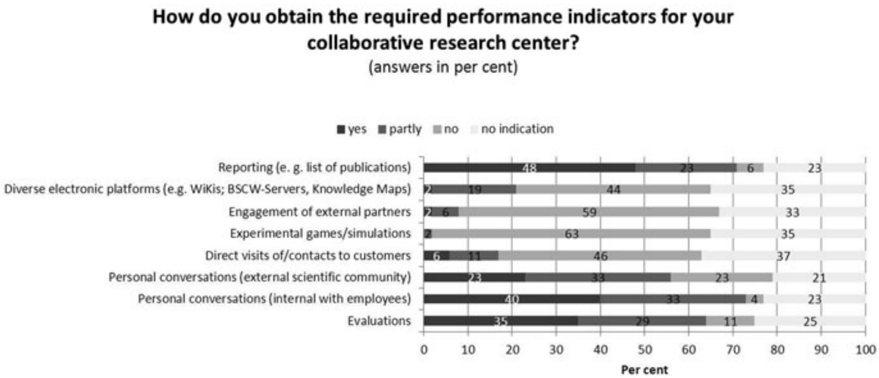


**Fig. 6** Methodology used in the context of performance measurement in CRC

indicated to collect the indicators monthly. CoE-specific data revealed the following results: 56 % collect the performance indicators on a yearly basis, 22 % sporadically and 11 % monthly (cf. Fig. 5). Referring to the yearly collection of indicators, one can assume that the majority of respondents from CoE and about one third of the respondents from CRC uses the results preliminary in terms of yearly status reports.

Asking for methodologies used in the context of performance measurement, the following items can be highlighted, because they are used/partly used in CRC. Personal internal conversations with employees and personal external conversations with the scientific community are broadly used as well as reporting and evaluations (cf. Fig. 6). The two most common forms of obtaining performance indicators in CRC are reporting (used by 48 % of all participating CRC) and personal internal conversations with employees (used by 40 % of all participating CRC).

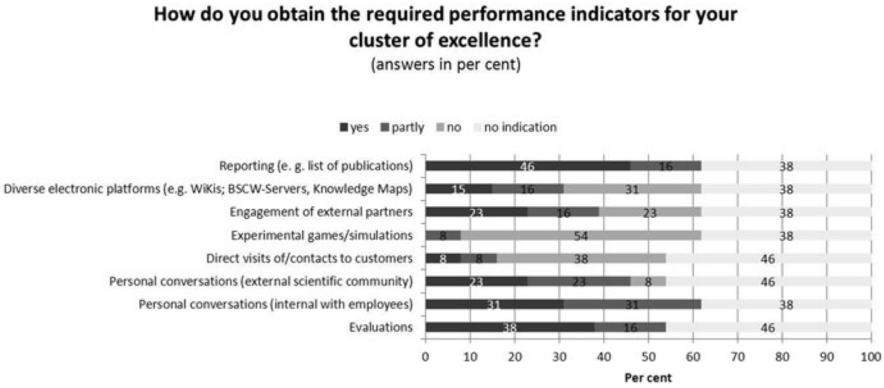


**Fig. 7** Methodology used in the context of performance measurement in CoE

With reference to the used/partly used methodologies among CoE participants, reporting, personal internal conversations with employees and personal external conversations with the scientific community as well as evaluations are indicated (cf. Fig. 7). The two most common forms thus constitute reporting (used by 46 % of all participating CoE) and evaluations (used by 38 % of all participating CoE). In comparison to the answers of the CRC it is astonishing that 23 % of the CoE participants obtain performance indicators by the engagement of external partners and 15 % indicate to receive indicators via diverse electronic platforms such as WiKis or knowledge maps.

In the context of an additional open question in this section of the survey, the participants could indicate a favorite method for the strategic target/performance comparison of their respective CRC/CoE. It has to be underlined that the majority of speakers and chief executive officers did not give a qualitative answer. Those participants who answered the question mentioned methods like: SWOT-analyses, project controlling, workshops to discuss results and targets formulated in the funding agreement as well as qualitative methods such as interviews with employees. Apart from that, keeping an eye on competitors (e. g. other CRC or CoE) and their superordinated research targets was named by one respondent, revealing the existence of benchmarking aspects. Overall, one can assume that holistic methods and concepts of target/performance comparison and performance measurement seem not to be widespread among the responding CRC and CoE.

## 6 Discussion of Methodological Approach

The study used a semi-standardized questionnaire to gain more empirical evidence about the application of performance measurement, the evaluation of scientific performance indicators by speakers and chief executive officers of CRC and CoE and the impact of both funding programs on the promotion of the research location Germany. The development of the entire survey – especially the interval scaled questions aiming at an evaluation of scientific performance indicators – based on contemporary findings in the topic of scientific performance measurement and on funding criteria for CRC and CoE. The study does not claim to be exhaustive in all aspects of scientific performance measurement. In order to counteract this fact, the survey provided the possibility of adding further aspects of performance measurement or scientific performance indicators in form of free text.

Considering the entire sample of all actively funded CRC and CoE ($n = 278$) the response quota of 23 % can be explained in particular by the following reasons: On the one hand, speakers and chief executive officers of CRC and CoE are confronted with enormous time restrictions regarding their daily business as science and management executives. On the other hand, questions about performance measurement and scientific performance indicators depict to some extent critical data which is not shared and disclosed by every participant voluntarily. Additionally, extend and design of the survey could be possible reasons for the response quota.

## 7 Concluding Remarks and Outlook

In the context of emerging New Public Management approaches as well as a changing understanding of performance measurement, the latter is adapted and extended in order to transfer successful concepts – preliminary implemented in profit-oriented organizations – to non-profit-oriented organizations. Special forms of non-profit-oriented organizations thus depict CRC and CoE in Germany, which can be described as public funded scientific collaborations integrating in particular interdisciplinary scientific partners.

With the presentation of results of an empirical study – addressed to the speakers and chief executive officers of all actively funded German CRC and CoE in 2010/2011 – the paper gives insights in how far performance indicators and performance measurement concepts are used to promote scientific processes in CRC and CoE as well as the respective research output:

Concerning the importance of a continuous performance measurement (such as: quality of research processes, originality and coherence of the scientific program and interdisciplinary cooperation) thirteen from fifteen items are evaluated as being important or very important among the respondents (cf. Fig. 2). The items are evaluated slightly worse among representatives of the CRC. One can assume that the importance of performance measurement seems to be greater among representatives of CoE than among representatives of CRC. A possible reason could be the average number of employees, because the responding CRC had fewer employees in average than the responding CoE.

Searching for KPIs that are suitable to measure the performance of CRC and CoE one can state that in average the performance indicator: quota of publications is evaluated as the most important indicator for scientific performance in CRC and CoE. This is not surprising, because publications constitute a superior scientific output in general. In addition to that the quota of successful PhD graduations and the number of international visiting researchers are further KPIs for both forms. As a differentiating example the number of awards is a KPI for CoE which is not as decisive for CRC. Vice versa the citation index is a KPI for CRC but not as crucial among CoE. At this point, one can assume that CRC are more performing in a classical scientific manner than CoE which perform slightly more in a project-oriented manner. Reflecting an overall interpretation of Figs. 2 and 3 one can consider that continuous performance measurement is of great importance in CRC and CoE whereas the listed performance indicators (cf. Fig. 3) seem not to completely meet the understanding of scientific performance indicators in the eyes of all respondents.

Considering the impact of the funding programs CRC and CoE on different aspects, the added value of both funding programs for the German science system is highlighted (cf. Fig. 4). Especially, both programs promoted the funding of young scientists what can be evaluated as a central achievement of the overall funding strategy formulated by BMFB, DFG and WR.

With regard to the frequency of collecting performance indicators, the majority of respondents indicated to collect data on a yearly basis. In CoE this frequency seems to be prevailing instead of a more diversified frequency among CRC (cf. Fig. 5). This could mean that performance indicators are particularly used in terms of a yearly status report.

Concerning methods implemented for collecting performance indicators, reporting, personal internal conversations with employees, personal external conversations with the scientific community as well as evaluations are noted by the majority of respondents. Hence, qualitative aspects of performance measurement such as conversations or interviews can be assumed as being important.

Overall, the results of the study revealed that a lot of speakers and chief executive officers are aware of the importance of performance measurement and respective KPIs of their CRC and CoE although holistic methods and concepts of target/performance comparison and performance measurement seem not to be widespread. Hence, more research is necessary, considering the development of performance measurement and performance management concepts in the context of CRC and CoE in order to set up frameworks that provide orientation for the management level also in terms of steering and regulation collaborative research.

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# Part II
# Next-Generation Teaching and Learning Concepts for Universities and the Economy

# A Training Model for University Teaching Staff

**Meike Bücker, Larissa Müller, Esther Borowski, René Vossen and Sabina Jeschke**

**Abstract** Several learning and training models have tried to explain the complex process of learning – one of them is the Learning Cycle of David A. Kolb. At the Center for Learning and Knowledge Management (ZLW) of RWTH Aachen University this model has been used as a didactical guideline for the consecutive training of university staff. Practical training experience showed that Kolb's Learning Cycle has to be modified for the training of higher education teachers due to different requirements of diverse target groups and varying teaching and learning contents. Based on scientific critique and the practical training experience of the ZLW, several specifications for the development of a new training model have been derived and are implemented in an innovative training model for the qualification program in order to promote an improved learning process for university teaching staff of the RWTH Aachen University.

**Keywords** Training Model · Reflection · Transfer · Kolb's Learning Cycle · Training for Teaching Staff

## 1 Introduction

The "shift from teaching to learning" has altered the idea of how learning processes can be improved. While some decades ago it was assumed that the quality of training situations is solely dependent on the expertise of the information-giver, this view was resigned in favor of learner orientation and the optimal construction of learning-friendly environments and learning communities [1]. In the case of didactical trainings for university teachers this shift has twofold implications: Firstly, the trainings should focus on the needs of the participants. Secondly, the principle should be incorporated by the participants in a way that they can design and conduct their own teaching with an orientation towards the students learning. However, this shift from teaching to learning is neither a sufficient concept for the whole process of

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learning, nor for the design of trainings for university teachers since it is only a basic concept. Learning and training models describing the ideal learning process in detail are trying to close that gap.

Actually one of the most popular, most used, most cited and most reviewed learning models is the Experiential Learning Cycle of David A. Kolb [2]. The Center of Excellence in Academic Teaching (ExAcT) at ZLW has used Kolb's Learning Cycle (KLC) as the guiding didactical principle regarding the design and the conduction of trainings for university teaching staff aiming to improve the teaching competencies of all personnel involved in teaching at RWTH Aachen University. Accordingly, the target group and the courses provided are very diverse: starting with training for student tutors, the program also addresses the training requirements of doctoral candidates, postdoctoral scientists and professors of all nine faculties of RWTH Aachen University.

Practical experience working with KLC in didactical trainings has shown that the model requires modifications for the specific case of training seminars for university teaching staff. Hence an adjusted training model for university teaching staff – based on past experience and empirical findings of teaching/learning research – is developed and explained in the course of this paper. The paper starts with a brief introduction to KLC, followed by scientific and practical reviews of the model. After the specifications for the model are deducted, the newly developed model is presented, whereby each step of the model is described and illustrated with relevant empirical findings of teaching/learning research. The paper closes with a short summary and a presentation of future prospects.

## 2 Kolb's Experiential Learning Cycle and Its Scientific and Practical Critic

David A. Kolb's work is based on the assumptions that learning is "the process whereby knowledge is created through the transformation of experience" ([2] p. 41) and that "knowledge results from the combination of grasping and transforming experience" [2]. Therefore KLC portrays two dual dialectical learning modes: Grasping experience through *Concrete Experience* and *Abstract Conceptualization* and transforming knowledge through *Reflective Observation* and *Active Experimentation* [2]. Direct or concrete experiences are the basis for observations and reflections. These reflections are incorporated and concentrated into abstract concepts from which new implications for action can be derived. These implications can be actively evaluated and provide a basis for creating new experiences [2]. Although being one of the most popular learning models, KLC has been widely criticized by the scientific community for its lack of flexibility [3], prior knowledge, educational targets [4] and emotions [5] as well as its insufficient consideration of the reflection process [6] and the social context [7].[1]

Empirical studies have proven the significance of flexible learning arrangements due to different learning mode preferences [8], the importance of educational targets [9], prior knowledge [1], emotions [10], the process of reflection [11] and the social context [12]. Jarvis [8] also criticizes that not all people learn from experience. This statement is also supported by the practical experience gained while applying KLC in the training process at the ZLW. Practical experience and feedback of the training participants have shown that KLC does not sufficiently meet the demands of the target group.[2] Another first-hand experience is that not all topics can be appropriately imparted with KLC. In some cases – where the subject is too complex and/or demanding to be taught through experiential learning in a short amount of time – it is useful to interchange theoretical input, practical input and reflection in order to promote the best possible learning process for the training participants. Additionally Kolb did not consider the lecturer-learner relationship and collaborative learning processes. So the model needs to be adapted to the specific social context of the given training situation which is a collaborative train-the-trainer situation.

The scientific and practical imperfections of KLC have shown that the model needs to undergo some adjustments in order to promote the best learning possibilities for the training participants and to achieve a development in the participants teaching competencies. Deducted from the above mentioned critics, the following requirements for a new training model are identified:

(a) transparent educational targets, (b) activation of prior knowledge and emotions, (c) flexible adaption to the needs of the diverse target group and specific thematic demands, (d) special emphasis on the process of reflection, (e) consideration of the social situation (the collaborative learning in a train-the-trainer-arrangement), (f) the transfer of the learned to actual teaching practice in the follow-up phase of the training.

## 3 A Training Model for University Teaching Staff

In order to meet the established requirements, the training model consists of the following elements: The clarification of educational targets, followed by the activation of emotional and cognitive prior knowledge, the flexible twofold learning stimulus taking the special needs of the target group and the collaborative learning situation

[1] Some of the critic presented can be moderated by taking Kolb's Experiential Learning Theory into account (e. g. [13]). But since this paper only deals with KLC, the match of model and theoretical background is not important for the development of the new model and therefore not considered in this paper.

[2] Especially engineers have criticized that they prefer being theoretically instructed before performing related tasks. This impression is also supported by empirical findings stating that technically orientated individuals tend to favor grasping theoretical knowledge before going to practice [14].

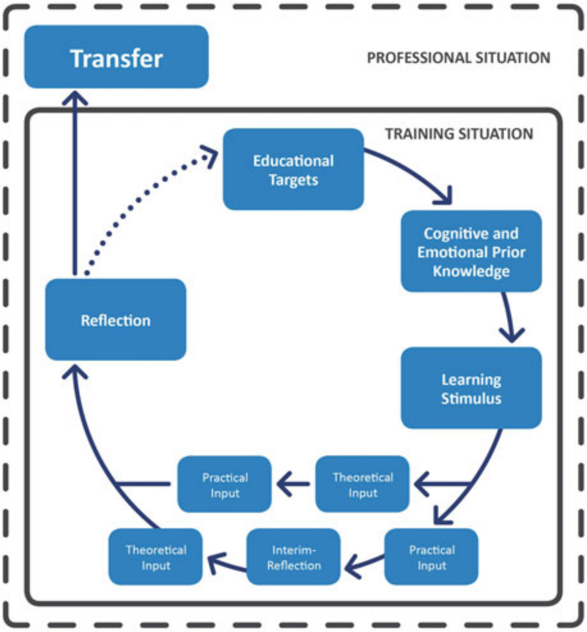


**Fig. 1** Training model for teaching university teaching staff

into account, the multifaceted process of reflection and finalized by the transfer of the learnings into teaching practice (see Fig. 1).[3]

The training process starts with the clarification of the *educational targets*. These describe competences that should be acquired by the learner at the end of the learning process [15]. The clarification of the educational targets, pointing out the potential gains and benefits of the learning session, facilitates the learning process because the learners attain information and are able to structure their learning. These statements are supported through empirical research claiming positive effects on students' motivation and achievement [9]. The outlining of the educational targets is helpful for the next step - the activation of emotional and cognitive prior knowledge.

Ausubel [16] has famously stated that the most important aspect influencing learning is what the learner already knows. This is the combination of *cognitive prior knowledge* (knowledge, skills or abilities) and the *emotional knowledge* in form of experiences and emotions connected with the content. Studies have shown that learner's previous learning needs to be activated in relation to new contents in order to effectively process information, because if this activation is not guaranteed, surface learning can occur [17]. Through the activation of former experiences emotions are stimulated as well, which is important because when emotions are engaged, the brain

[3] The model is used as a guiding principle for the design and conduction of the whole training as well as single learning episodes.

releases neurotransmitters that mark the event and make it significant. This focuses attention and facilitates learning [1]. By verbalizing this cognitive and emotional knowledge the learners activate what they already know and thereby facilitate their learning [18]. Also the trainer obtains valuable information of the participants' prior knowledge and is therefore able to adapt the learning content and explanations to prior knowledge and the experiences of the participants and thereby prepare them for the learning stimulus properly.

Each *learning stimulus* consists of a theoretical (instruction based) and a practical (experience based) input, since learning is best facilitated when both learning forms are combined [18]. During the theoretical input the trainer presents contents and didactic prepared solutions to solve typical problems while the participants are actively listening. During the practical input the trainer rather arranges learning environments in a way that allows the learner to acquire the new learning contents actively and independently. Because research and practical experience have shown that different individuals perceive and process experiences in different preferred ways [1], it is necessary to vary the sequence of theoretical and practical input in a flexible way according to the needs of the target group and/or specific topics.[4] When both learning stimulus are completed, the reflection of the learned takes place.

In the context of this model reflection is understood as a process of (shared) thinking about previous experiences for the purpose of expanding one's opinions and making decisions about improved ways of acting in the future [19]. Inherent to this definition are three types of reflection: self-reflection, social reflection in the group and transfer-orientated reflection. During the self-reflection the learner makes sense of the experiences of the learning stimulus phase. Afterwards the learner shares his insights with the group in the social reflection. By listening to other participants, the learner deals with the perspectives and (potential controversial) insights of fellow university teachers. During this social construction process with peers, normative expectations defining the role as "university teacher" are discussed and clarified. A special emphasis lies on the transfer-orientated reflection where the learner decides which insights, gained through learning stimuli, self-reflection and adjusted by social reflection, he wants to transfer into teaching practice. The threefold process of reflection prepares the learner for the aftermath of the actual training situation - the transfer.

*Transfer* means the process of integrating, adapting previously learned knowledge and action patterns into professional daily teaching routine. The learning experience is realized in the professional teaching situation and put on probation. The transfer effect is accomplished when the training participants have enhanced their teaching competencies [20]. The transfer process is facilitated by the use of a learning journal which the participants continually use to write down which ideas they want to put

[4] If the trainer - on the basis of target group and/or content specifics - decides to start with the theoretical input, it is followed by the practical input and then leads to the phase of reflection. If the trainer begins with the practical input, a short interim reflection is inserted before the theoretical input is given (see the loop in Fig. 1).

into practice, the multifaceted process of reflection, and handouts summarizing the important contents of the training.

# 4 Summary

In the following it is summarized how the training model meets the above presented requirements: (a) The clarification of the educational targets marks the first step of the training process. (b) The second step consists of eliciting of cognitive prior knowledge and of emotions. (c) The needs of the diverse target group and specific thematic demands are taken into account through the flexible arrangement of learning stimuli and reflection: Corresponding to the target group and topic specifics the trainer decides whether to start with the theoretical or the practical learning input and adjusts the reflection accordingly. (d) The phase of reflection plays a crucial role in the training model, consisting of three parts: the self-reflection, the group reflection and transfer-orientated self-reflection. (e) The social situation is contemplated through the use of practical inputs where collaborative learning is promoted and through the group-reflection where the participants benefit from insights of the peer group. (f) The transfer to the follow-up phase of the training supports the aim to develop the teaching competence in the participants' own teaching situation. The presented training model does not claim to explain the complex process of learning. It is rather a training model derived from practical experience and literature review best suited for the training of teaching staff at RWTH Aachen University. The training model is still in a testing and adjustment phase since empirical examination of the model has yet not been conducted. Its practicality will be reviewed by the trainers and the model will also be discussed with the training participants. In the course of the professional training evaluation the model will also be scientifically tested in regard to its accuracy and usefulness. Furthermore it will be analyzed in detail which group of persons prefers which loop of the learning stimulus in order to develop empirically resistant guidelines for the accurate use of the model. For this end a comparative study highlighting the specifics of disciplinary cultures will be conducted. The results of this study will be integrated as concrete training recommendations in the didactical framework of the training model.

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# How to Prepare Academic Staff for Their New Role as University Teachers? Welcome to the Seminar “Academic Teaching”

**Meike Bücker, Esther Borowski, René Vossen and Sabina Jeschke**

**Abstract** The basic university teacher training at RWTH Aachen University is the 2-day seminar “Academic Teaching” which addresses the qualification needs of (mainly) doctoral students who are short on teaching experience. The target of the training is to set a starting point for the development of the participants’ teaching competence. The orientation on a five-stage development model of teaching competence serves as the content structure of the seminar, suggesting that different topics are important for the participants at different stages of their teaching competence development. The didactical method to convey these contents is the constructivist ExAcT training model based on current findings of pedagogical psychology and neuroscience. In the following sections it will be described how the goal of teaching competence development for new university teachers is attained by considering development stages of teaching competence through the content structure and by using the training model as didactical method in the seminar “Academic Teaching”.

**Keywords** University Teaching Staff · Teaching Competence · Development Models · University Teacher Training

## 1 Introduction

Until 1989 there were no documented discussions about the criteria of teaching quality at German higher education institutions [1, p. 53]. In the face of the Bologna Reform, the discussion on teaching quality has deepened and progressed. Since then university didactics and competence requirements have become two of the most important issues and research fields in higher education, drawing more and more focus on teaching quality in the university context [2, p. 3 f.].

One indicator of teaching quality is student-orientated teaching: instead of supply-orientated teaching, student centering is pursued. Student-orientation implies activating students, clarifying learning goals and competence orientation. For

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numerous universities this means a shift in didactical paradigm [3, p. 10]. The realization of student-orientated teaching is also central with regard to the (international) competitive position of German universities (Wissenschaftsrat 2005). But which factors are necessary to gain high teaching quality and to secure this quality of teaching in a sustainable manner [2, p. 6]?

In the course of this educational quality debate, the professionalization of teaching staff becomes increasingly important. It requires competence development through university didactics. The focus herein is not the development of a patent remedy for teaching quality, but to clarify the relevance of university didactical competencies for scientific staff in order to promote quality improvement in teaching [2, p. 1 f.]. Those didactical trainings are not only important for young scientists, but also for experienced teaching staff who need further didactical training as well [4, p. 4 f.]. To solve this challenge an increasing number of higher education didactic initiatives have evolved aiming to professionalize and improve teaching [5, p. 2].

One of these initiatives is the "Quality Pact for Teaching" of the German Federal Government and the Länder.[1] The intention of this initiative is to ameliorate study conditions, the quality of teaching and mentoring for students at institutions of higher education The overall goals of the program are to achieve a better student-to-staff ratio at institutions of higher education, to provide support in the qualification or further training of staff as well as to ensure and further develop the quality of education at institutions of higher education. This objective can only be achieved by additional qualified staff in the areas of teaching, mentoring and advisory services. The Federal Government provides the program with funds of about 2 billion € between 2011 and 2020. Funding is granted to a total of 250 individual and collaborative projects: The 78 universities (RWTH Aachen University being among them), 78 universities of applied sciences and 30 colleges of art and music chosen for funding have to put their plans to improve teaching and study conditions into practice until 2016.

In the scope of the Quality Pact, the Center of Excellence in Academic Teaching (ExAcT)[2] was installed at the Center for Learning and Knowledge Management (ZLW)[3], which serves as the center of higher education didactics at RWTH Aachen University. The Centre of Excellence acts as a central and individual contact for questions from teachers as well as an intermediary to develop and apply differentiated teaching methods and exams types. The goal of ExAcT is to foster teaching competence through the comprehensive qualification program (ExAcT Qualification). Aim

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[1] The Federal Republic of Germany consists of 16 federal states, the so called "Länder".

[2] For further information visit the project website: www.exact.rwth-aachen.de.

[3] The ZLW heads various central projects and institutions for teaching and further education: It coordinates the Centre for Further Education with the aim to develop excellent and highly qualified teaching staff. Together with its partners from the Technical University Dortmund and the Ruhr-University Bochum the ZLW runs a national Competence and Service Center for Teaching and Learning in Engineering Sciences called "TeachIng.LearnIng.EU". Also the student laboratories of the RWTH, RWTH Education Labs, are located at the ZLW und are organized jointly with partners from university and industry. In the context of E-Learning, the ZLW ran the projects BlendXL and Role. Other notable projects are KISSWIN, CSP or HTBP. For further information visit the ZLW-website: http://www.ima-zlw-ifu.rwth-aachen.de/en/institute_cluster/institutes/zlw.html.


**Fig. 1** ExAcT qualification program

of this project is to promote tailor-made qualification of the teaching staff at RWTH Aachen University for continuous improvement of their teaching performance. Accordingly, the target group and the courses provided are very diverse: starting with training for student tutors, the program also addresses the training requirements of doctoral candidates, postdoctoral scientists and professors of all nine faculties of RWTH Aachen University.[4]

To address those diverse training requirements, the qualification program is structured as a matrix of four different levels of specialization and five thematic foci (see Fig. 1).

The qualification starts the *basics* module for (future) university teachers with few or none teaching experience, continues with the in-depth-module (*extensions*) for university teachers who wish to extend their skills and expertise for a specific teaching situation, addresses discipline-specific demands of university teachers and whole faculties in special subject-related modules (*advanced*) and offers *individual teaching coaching* for (junior-) professors and mid-level faculty members with teaching responsibility. Following those different specialization levels, various seminars and workshops are offered with the following thematic foci: university didactic classics, media in teaching, diversity in teaching and soft skills in teaching.

Didactical trainings are of central importance for new university teachers. The scientific reputation system prioritizes research over teaching [3, p. 14, 6, p. 52],

[4] As far as personal designation in the content is only given in male form, it equally refers to women and men.

which is particularly a problem for early-stage scientists. They are heavily stressed by their new teaching duties and are simultaneously exposed to performance pressure regarding their research activities, since they have just started their scientific career and need to prove and establish themselves. Young scientists are often insecure about their new role and the connected duties and thus feel left alone to face all these expectations in a short amount of (working) time, resulting in a quality decrease both in research and especially in teaching [7, p. 198 ff.].

Accordingly, this special group needs training that provides them with the basics of university didactics. This supports them in their first steps in teaching and helps them to identify with their new role as a student-orientated university teacher. In the ExAcT Qualification program, the seminar "Academic Teaching" gives the participants an overview and an introduction into university teaching within a 2-day training. The target group of "Academic Teaching" consists of (future) university teachers of all disciplines with none or few teaching experience. Per seminar ten participants are educated by two trainers. The goal of "Academic Teaching" is to set a starting point for the development of teaching competence. Within the ExAcT qualification matrix the seminar is located on the basic level und belongs to the university didactic classics series.

In the following sections of this paper the concept of "Academic Teaching" regarding its targets, contents and didactical framework will be presented. At first, the main target of Academic teaching, the development of teaching competence will be regarded. Therefore, several teaching competence models will be reviewed, followed by an evaluation of development models, which categorize the stages of teaching competence development. The content structure of the seminar is orientated towards these different teaching competence development stages, so that each development stage has an associated content episode. The contents of the seminar are conveyed by using the ExAcT training model which will be described thereafter. The interaction of content and the training model will be exemplified by the seminar episode "handling conflicts with students". The paper will close with a short summary, prospects for future developments and arising research questions.

## 2 Teaching Competence

The goal of the ExAcT qualification program is to (further) develop the teaching competence of the training participants in order to attain teachers to teach student-orientated. In order to elucidate what teaching competence signifies, the term competence has to be defined. the following literature review of different teaching competence concepts will give an impression on the competences required to fulfill the role as a university teacher. As teaching competence evolves with time, development models of teaching competence will be introduced.

### *2.1 Competence*

The term competence has found its way into everyday speech and is widely used in scientific literature. Nevertheless an uncountable number of definitions and multi-faceted fields of application hinder a joined understanding of the competence concept [2, p. 7]. One of the main issues is the difference between the terms "competency" and "competence". Sadler [8] defines the difference as follows: While a "competency" stands for an identifiable skill or practice, "competence" is assumed to consist of a large number of discrete competencies which can be tested independently by objective means. It can be said that competence encompasses being able to choose from and then compile a set of competencies to attain a specific goal within a specific context. In short, competence is composed of various competencies. Here, it has to be considered that the whole (competence) does not necessarily equate to the sum of the parts (the competencies). Concluding, competence is more than just an umbrella term for an accumulation of competencies. Competence can only occur within complex situations, and not componentially [8, p. 13]. To sum up, a competence is

> [ . . . ] a cluster of related knowledge, skills and attitudes that affects a major part of one's job (a role or responsibility), that correlates with performance on the job, that can be measured against well-accepted standards, and that can be improved via training and development." [9, p. 50]

Thus, a competent person makes "multi-criteria judgments that consistently are appropriate and situation-sensitive" [8, p. 21]. After clarifying the term competence, the competence term will be transferred to the professional situation of teachers. In the following, it will be referred to teaching competence instead of teaching competencies, since the term competence includes all (sub-)competencies that a teacher possesses.

### *2.2 Teaching Competence*

Which competencies and competences are required for university teaching staff? In the last years this question has been targeted in the German university didactical research and practice and some competence models have been developed.

For *Webler* [1, 10] the term "teaching competence" does not only include knowledge and action aspects, but also moral concepts and ethical attitudes. From his position, teaching competence derives from the capability to connect knowledge, methods and behavior with the learning requirements and possibilities of the students [1, p. 69]. Three competence fields are identified for university teachers: **Personal competence**, **social competence** and **professional didactical competence**. Personal competence includes competencies like role clarity, ability to reflect and positive thinking. The social competence consists of competencies such as the ability to (meta-)communicate and the addressee orientation. The professional didactical competence involves the following eight competencies: (a) planning of courses,

(b) didactic methods, (c) media, (d) counseling, (e) qualification competence, (f) assessment competence, (g) evaluation competence and (h) field competence. It has to be considered that Webler [1] developed his teaching competence model on the basis of legal statements (Hochschulrahmengesetz § 7)[5] leaving those competence profiles rather normatively deduced than empirically derived.

*Wildt's* [11, p. 22 f.] work on teaching competence centers especially soft skills. According to him, teachers should qualify students for their post-studies professional working life, in other words to secure the students' employability. Therefore teachers are not only committed to convey knowledge and professional methods, but also to foster the soft skills like self-regulated learning and "academic competences"[6] of the students. This can be best accomplished by using experience and problem-based learning situations and the orientation on learning outcomes, which are competences that should be acquired by the end of the learning session. Referring to a wide spread competence classification, he categorizes four competence types: **Professional competence**, **method competence**, **personal competence** and **social competence**, clarifying that this competence classification needs to be specified with regard to the professional situation of university teachers. Above all, Wildt criticizes that the teaching competence debate lacks an elaborated theoretical background.

*Schulmeister* [12, p. 125 ff.] finds four core competences that should be developed by young scientists in the course of their teaching career: **Planning competence**, **performance competence**, **methodical competence** and **media competence**. Planning competence includes the ability to develop and convey learning contents in the institutional university context. Performance competence helps to identify the leadership role in the learning situation. The didactical repertoire of single methods and didactical strategies is incorporated in the methodical competence, whereas media competence means the ability to use new media in teaching. Through evaluation, Schulmeister [12, p. 128] also found out that learning theory, methodology and the specific learning culture are overarching concepts (called meta-aspects) that connect the above acknowledged competence spheres. In relation to many other teaching competence models, this model holds the advantage of being empirically tested, but it remains unclear on which educational theory the competence division and formulation are grounded [13, p. 59].

The teaching competence model of *Chur* [14, 15] identifies qualification requirements for teachers in the following competence fields: **Scientific qualification**, **didactical qualification** and **soft skills**. Scientific qualification is needed to illustrate the contents and methods of their particular scientific (research) field. Didactical qualification includes causal knowledge on teaching and learning[7], cooperative-delegate

[5] For further information see http://www.gesetze-im-internet.de/hrg/BJNR001850976.html.

[6] Academic competence relates to the accomplishment of academic performance requirements.

[7] Teachers should be able to position themselves with their own profile and their role as university teacher.

leadership skills, supporting the learning on different levels of action (contract situation, context conditions, curricular structures and courses)[8] and the ability for systematic communication [15, p. 187 ff.]. The competence field soft skills consists of being capable of acting in challenging situations ("active orientation"), acting purposefully, self-directed learning and to have social competences. Chur [14, p. 208] clarifies that the scientific qualification has to be achieved in the field of faculties, whereas didactical qualification and soft skills can be acquired in the frame of further training.

*Brendel et al.* [13] examined the competences of university didactical training participants. They analyzed various documents – consisting of university didactics seminars, hospitations and counseling of university teachers – regarding what abilities teachers aim to acquire in the university didactics qualification process, how these abilities can be concentrated into competences and how those competences are related to each other. Brendel et al. deduced the following competences: having **knowledge on the conditions of sustainable teaching and learning processes** and the **ability to implement those conditions**, the ability to **perceive and manage social processes**, to have **role clarity and self-reflectivity**, the competence to lead, as well as **soft skills** and **innovation competence**.

*The UK Professional Standards Framework for Teaching and Supporting Learning in Higher Education* [16] distinguishes three primary dimensions: **Areas of Activity** (ranging from activities like designing and planning of learning sessions to continuous professional development and training), **Core Knowledge** (knowledge on different aspects like learning methods and technologies or evaluation methods) and **Professional Values** (from the valuation of the learners to the use of evidence-based approaches). These competences are derived from the Higher Education Academy's existing Accreditation Scheme and can therefore be understood as a framework for standards aiming at the professionalization of learning and supporting learning in higher education.

Table 1 gives a structured summary of the presented teaching competence models, differentiating the identified competences into personal, social and didactical competence.

These different approaches gives an overview of the competence repertoires teachers (should) have in order to provide good teaching. Some of the models [1, 10–12, 15, 16] rather regard what competences university teachers should have or develop in the face of their contextual conditions whilst another model [13] regards the actual competences teachers already have. The first could be called top-down-competence models, because the context determines the desired competences, the latter could be entitled as bottom-up competence models since the competences of teachers are examined in practice and condensed and clustered into a model. It is obvious that most models employ a top-down-approach whereas bottom-up models have been empirically neglected. The further investigation of bottom-up approaches and the

[8] The teachers hast to see themselves as a facilitators of student learning through transparent learning and competence goals orientated towards the Learning Outcome.

**Table 1** Summary of teaching competence models

| Author/ competencies | Personal competence | Social competence | Didactical competence |
|---|---|---|---|
| [1, 10] | *Personal competence*<br>Role clarity, ability to reflect, positive thinking | *Social competence*<br>Ability to communicate, addressee orientation | *Didactical competence*<br>Planning of courses, didactic methods, media, counseling, qualification competence, assessment, evaluation, field competence |
| [11] | *Personal competence* | *Social competence* | *Professional competence, method competence* |
| [12] | *Performance competence*<br>(leadership ability) | | *Planning competence*<br>(develop and convey learning contents), *methodical competence*<br>(didactical methods and strategies), *media competence*<br>(ability to use new media in teaching) |
| [14, 15] | *Didactical qualification*<br>(cooperative delegate leadership skills)<br>*Soft skills*<br>(active orientation, act purposefully, learn self-directed) | *Didactical qualification*<br>(ability for systematic communication)<br>*Soft skills*<br>(social competences) | [*Scientific qualification*][a] , *didactical qualification*<br>(causal knowledge on teaching and learning, support learning) |
| [13] | Role clarity and self-reflectivity, leadership abilities, soft skills, innovation competence | Perceive and manage social processes, soft skills | Having knowledge on the conditions of sustainable teaching and learning and the ability to implement these conditions |
| [16] | | | *Areas of activity*<br>(designing and planning of learning sessions, continuous professional development and training), *core knowledge*<br>(knowledge on learning methods and technologies or evaluation methods), *professional values*<br>(from the valuation of the learners to the use of evidence-based approaches) |

[a]The scientific, professional competence should be an independent competence. But "Academic Teaching" does not train the scientific, professional competence and therefore it is not included as individual column in this table.

combination of top-down and bottom-up competence models remains a challenge for future research.

In our case, teaching competence has a normative and functionalist notation. Therefore ExAcT follows the differentiation of Webler, distinguishing personal, social and didactical competence (see Table 1), because it allows the integration and allocation of the competence division of other authors (see also [17]). So, passing through the ExAcT qualification program, the teachers continually develop their teaching competence – not only in the field of their didactical competences, but also in their personal and social competence since these make up an important part of good teaching. Accordingly, the ExAcT Qualification program addresses the development of teaching competence by trainings that aim to advance personal competence, social competence and didactical competence including planning, method, media and evaluation competence.[9]

## *2.3 Development Stages of Teaching Competence*

Teaching competence and its sub-competencies do not develop overnight. A professor with 40 years of teaching experience teaches differently than a teaching newcomer – at least they differ in their teaching style, their attitude towards teaching and the interaction with students [18, p. 16 ff.]. But why is that the case? Development models suggest that university teachers run through typical phases until they have developed teaching competence [19, p. 17].[10,11]

The development model of *Nyquist & Sprague* [20] assumes that in the course of their teaching responsibilities, the focus of university teachers shifts from the **own person** to **professional contents** and finally leads to a focus on **student-learning**.

In his empirically tested development model, *Kugel* [5] describes phases that slightly differ from stages of Sprague & Nyquist [20]. Alike them he distinguishes three superordinate stages: The attention on the **own person** (popularity, competence), attention on **discipline characteristics** (content) followed by the **attention on students**. The last stage includes three additional sub-stages: At first, the teacher sees students as passive consumers of his knowledge transmission. Then the teacher understands, that students are rather active learners followed by the phase where the teacher realizes that students need to learn self-directed and independently to make the best of the learning situation.

[9] A paper on the development of the ExAcT competence model is contemporary in progress.

[10] The presented development models do not explicitly regard the development of the construct teaching competence, but the parallels are clear since they regard the (further) development of university teachers.

[11] It has to be acknowledged that the development of teaching competence is not necessarily connected with time. Some university teachers do not develop teaching competence at all or do not teach accordingly though they would have the competences to do so.

**Table 2** Development models of teaching competence

| Sprague & Nyquist | Kugel | Böss-Ostendorf & Senft |
|---|---|---|
| 1) Own person | 1) Own person | 1) Own person and new role |
| 2) Professional content | 2) Discipline characteristics | 2) Content |
| 3) Student-learning | 3) Attention on students | 3) Didactics |
| | a) Students as passive consumers | 4) Student learning |
| | b) Students as active learners | |
| | c) Students as self-directed learners | 5) Self-directed learning |

Another development model is the model of *Böss-Ostendorf & Senft* [18] that differentiates five phases of university teacher development. In the first phase the teacher newcomers are concentrated on their **own person and their new role**. In teaching situations they are nervous and concerned whether the students accept them or what to do if they don't. Another concern for the new teachers is how to prevent the students from recognizing their lack of knowledge. In the second phase the teachers realize that the students rather focus on the **contents** than on the teacher. The teachers feel relieved and concentrate on the content, which means that they "hide" behind the contents to conceal their still virulent insecurities. This phase could be called lecturer-orientated information transfer. When the teachers comprehend that the students' attention is neither on them nor on the content and that they have left the students behind, they enter the third phase. The teachers figure out that they need means and methods to regain the students' attention. They are able to concentrate on **didactics** because they feel more secure since they have demonstrated their professional competence. They widen their self-focus and consider the significant others – the students. In the fourth phase, the teachers have developed a stress-free and cooperative teaching style. They concentrate on the students learning and adapt the course contents on the students' ability to process information. They increase their self-confidence and emphasize the quality of their teaching over the quantity. In the fifth phase, teachers have understood that learning is best facilitated when the content has been discovered and developed by the learners themselves. They design learning environments for **self-directed learning**, perceive students as a (learning) group and use student communication and a variety of methods and media for the achievement of their learning goals [18, p. 17 ff.].

The presented development models are summarized in Table 2.

The three development models accentuate that not all teachers pass through all development stages, and that the stages are not necessarily passed in the presented sequence. Whether university didactical trainings foster teaching competence development is yet an open research question, but there is evidence that systematic reflection on teaching (in form of didactical trainings and coaching) promotes the development [21]. The presented models assume that developments happen especially at the beginning of the teaching career. This implicates that didactical trainings for new teachers need to consider that they might not be open to the students' needs, because they are still occupied with themselves and their new role as university teachers [5, p. 11].

For the seminar Academic Teaching the models described above are combined into a development model that consists of four steps:

1. the focus on new role as a teacher,
2. the focus on the content,
3. the focus on didactics and
4. the focus on the student.

The reason for this division is that in our opinion student orientation is closely connected with the aim to design learning environments that foster self-directed learning.

Concluding, the minor goal of "Academic Teaching" is to set a starting point for the didactical competence and its components (planning, method, media and evaluation competence). In order to reach the major goal, to evolve competencies that are required to create learning environments in which students are able to learn context-related, actively, situated and process-orientated, the seminar also focuses on their personal and social competence. It should be considered that trainings for new teachers cannot start directly with the major goal of student-orientated teaching, because new teachers might not be open for it since they are in early development stages and too occupied with themselves. But at the same time new teachers should be sensitized for the need to teach student-orientated. The basic seminar "Academic Teaching" gives new teachers an overview of the development that university teachers (should) undergo and provides them with the knowledge and abilities required to develop from one stage to another. This helps them to acquire knowledge on the most important aspects of good teaching by a speeded-up pass through the stages for teaching competence.

## 3 Contents of Academic Teaching

In tradition of the development models for teaching competence, the content structure of the seminar simulates the development from a teaching novice to a student-orientated teacher. The content structure is orientated to our modified development model consisting of the focus on the new role as a teacher, on content, on didactics and on students. The seminar starts with the focus on teacher and is followed by the focus on content and the focus on didactics on the first day. The second day includes the focus on students and also course planning that implies the knowledge and abilities of all other foci.[12]

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[12] Some of activities - like the introduction to the seminar, the getting acquainted, activating games as well as the feedbacks are not included in this description. They are not specific for Academic Teaching, but for all trainings.

## 3.1 Focus: Teacher

The literature on teaching competence development suggests that new teachers need to over-come their self-focus to be open for student orientation. Accordingly, the seminar starts with the episode *teaching competence*. This section involves a discussion on competences that a good university teacher should possess, since role clarity is an essential part of teaching competence, as revealed in the literature. This is of particular importance, because many of the training participants have not yet reflected upon their new role and the corresponding abilities and responsibilities.

Subsequent to this reflection on teaching competence, the participants get a *video feedback*. Prior to the training, the participants are asked to prepare a 5 min lecture to be held and recorded in the seminar, which is later analyzed in a peer-to-peer session. Firstly, the analyzed participant gets the possibility to reflect upon himself. Afterwards the peer colleagues give their feedback which is complemented by professional feedback of the seminar trainers.

Subsequently the participants learn about *demeanor in teaching* – including empirical findings and recommendations on applying voice, gesture and mimics.

The focus on teacher – as a first step in teaching competence development – helps to develop the participants' teaching competence in the fields of personal competence, by identifying strengths and weaknesses in their teaching performance, and their social competence by fostering the ability to give and receive feedback. Thereafter the focus of the seminar widens from the individual perspective to the teaching contents.

## 3.2 Focus: Content

The focus on content marks the second stage of teaching competence development and concentrates on the in the imparting of professional contents. The focus consists of the learning episodes "learning goals" and "structuring of learning contents". The episode on *learning goals* emphasizes that transparent learning goals are crucial for assessing the academic performance. It also points out that learning goals describe the competencies that should be acquired by the learner at the end of the learning episode. For the learning goals to be effective, they need to be transparent to the students, which is achieved by pointing out the potential gains and benefits of the learned. Thereafter, the cognitive learning goal taxonomy of Bloom [22] and its simplified version of Blum [23] are presented. Blum's [23] taxonomy highlights that learning goals can operate on different levels: on the level of knowing and understanding, on the level of using and transacting knowledge as wells as on the level of interpretation and review of the contents. The participants discover that learning goals can also be differentiated regarding their generality by distinguishing strategic, indicative and operational learning goals [24]. In this section the training participants are asked to develop three learning goals for their upcoming lesson. The learning goals episode contributes to didactical planning and evaluation competence of the participants, since learning goals are essential for planning and evaluating courses.[13]

The episode *structuring of learning contents* presents methods to gather, select and structure the contents for courses. Two approaches to structure content – the inductive and the deductive approach – are discussed with regards to their advantages and disadvantages. Furthermore it is alluded that due to the primacy and recency effect, the most important contents should be delivered – or at least repeated – in the beginning and in the end of the learning session [25]. This promotes the development of teaching competence with regard to didactical planning and evaluation competence.

The following focus on didactics[14] compiles how the contents can be conveyed to the students by using didactical methods.

## *3.3 Focus: Didactics*

The focus on didactics includes the episodes *presentation* and *teaching and learning arrangements* that aspire to improve the teaching competence in the fields of didactical planning, method and media competence and the social competence of the participants via teamwork in the working phases.

The *presentation* episode addresses how learning contents are best presented to students and discusses the design of transparencies and (power-point) slides, the creation of interactive worksheets and the use of media.

During the episode *teaching and learning arrangements* the participants learn that there are many opportunities to convey contents to students: instructional teaching, task-related teaching and cooperative teaching. Instructional teaching signifies the "classical" teaching situation where the teacher presents the contents while the students are rather passive. Task-related teaching includes teaching trends like research-based or experience-based learning, where the students solve a realistic task. Cooperative teaching emphasizes dialogical learning and can be realized through problem-based and collaborative learning[15]. Besides discussing the basics of each teaching and learning arrangement as well as their respective opportunities and risks, it is also considered how these different arrangements can be adapted in varying group sizes. This focus puts an end to the first day of the training and opens the scope for the student focus on the second day.

[13] Learning goals are important for the evaluation, because evaluation is concerned with the achievement of the defined learning goals.

[14] Didactics is a term describing the study of the relationship between learners, teachers and educational subject knowledge.

[15] Problem-based learning is special case, because it is rather a mixture of task-related and cooperative teaching.

### 3.4 Focus: Students

In the focus on students, the subjects contemporary students, communication, activation of students, interaction with students, an introduction to neurodidactics and feedback are regarded. In the episode *contemporary students*, the participants talk about the characteristics of contemporary students and reflect upon their role as a teacher once again. It is emphasized that teachers – especially in times of new media – function rather as a broadcaster of knowledge than a knowledge repository. The personal competence as well as the didactical competence is trained through this reflection.

The following episode concentrates on the basics of *communication*. Participants are sensitized over possible misunderstandings and the role of feedback in communication which is to secure whether the intended message/information of the sender is understood by the receiving side, thereby contributing to the development of the teacher's social competence.

The episode *activation of students* starts with an introduction to motivation, contrasting extrinsic and intrinsic motivation and its connection with surface and deep learning[16] [26]. In this context, it is discussed what the teachers are ought (not) to do in order to achieve the students' deep learning. The use of questions (what questions can be asked, how should questions be asked and what can be done if nobody wants to answer) is emphasized in this episode, as well as other activating didactical methods (e. g. think-pair-share). Additionally, innovative activation methods with audience response systems (e. g. PollEverywhere or PINGO) are presented. The activation of students develops the teaching competence mainly in the field of didactical method competence, also broaching the didactical planning and media competence as well as the social competence.

The episode *interaction with students* contains two superordinate topics: handling conflicts with students and diversity in teaching. Handling conflicts with students includes the discussion which conflicts might arise (e. g. know-it-alls or people who are constantly chatting) and how these different forms of derangements can be handled appropriately (for further description of this phase see Sect. 5). The diversity episode starts with a clarification of the term diversity in the university context and aims at sensitizing the new teachers for the variety of students and their different needs (e. g. students with handicaps, migration background or family duties). This episode develops especially the social competence of the participants.

The following episode, *neurodidactics*, presents findings of the discipline neurodidactics that aims to integrate neuroscience and didactics. In the seminar, some of

[16] Surface learning "[. . . ] indicates the use of routine memorisation to reproduce those aspects of the subject matter expected to be assessed" [26, p. 595]. In contrast, the deep approach describes "active engagement with the content, leading to extensive elaboration of the learning material while seeking personal understanding" [26].

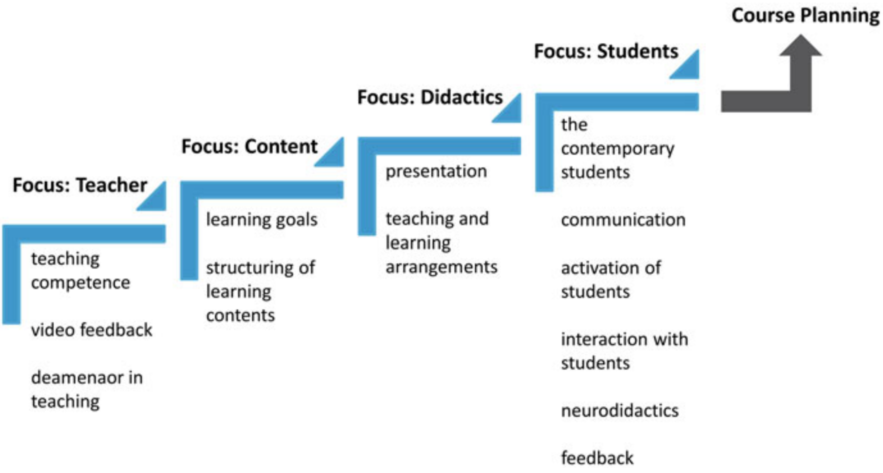


**Fig. 2** Content structure of academic teaching

those findings – linking learning and teacher behavior with brain activities – are presented to show participants who are critical to pedagogy and didactics that didactical statements are scientifically investigated.[17]

The last episode is on *feedback*. The participants get to know that feedback is important for teaching improvement and personal development and learn methods to seek student feedback independent from the official evaluation.

## 3.5 Course Planning

Course planning is a difficult task in teaching: it involves the knowledge of choosing and structuring contents and the knowledge of didactical methods and media. The participants become sensitized for the contextual, personal and interactional conditions that have to be considered before planning the course (e. g. room conditions, prior knowledge of the students, semester of the students). Afterwards the participants get to know different ways to design a curriculum (linear, exemplarily or lead by student interest). This episode primarily contributes to the development of teaching competence in the field of didactical planning competence.

Figure 2 summarizes the depicted content structure once again:

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[17] It has to be acknowledged that neurodidactics are criticized for its oversimplification of findings from neuro-science [30, 31]. Despite this critic, several prominent researchers from neuroscience and education believe that bridging the gaps is possible, leading to a fruitful mutual interaction, i. e. synergy [30–34].

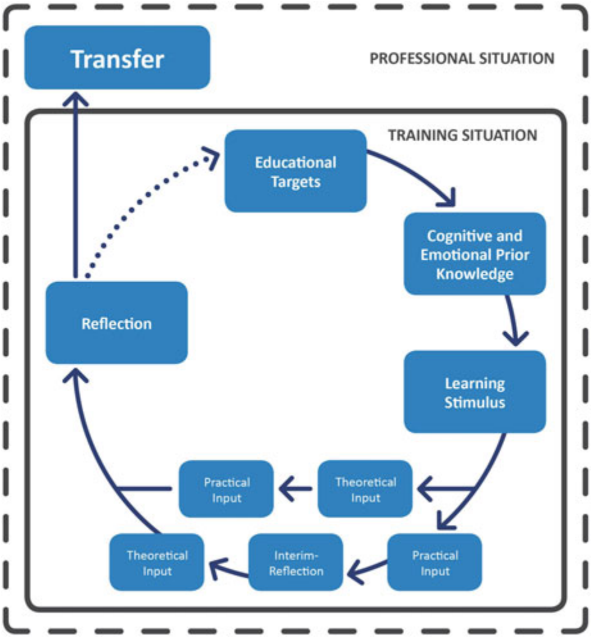


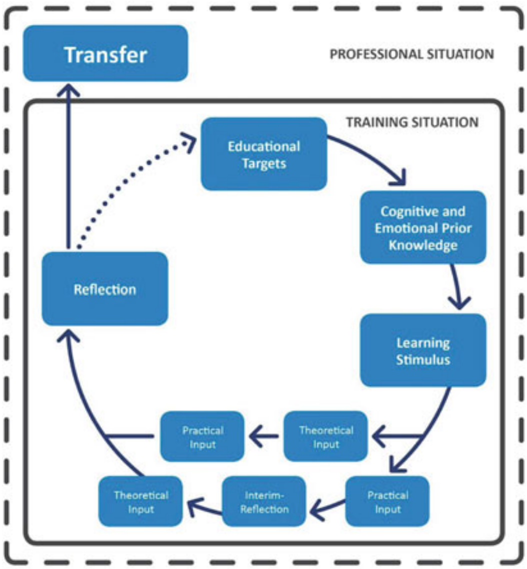

**Fig. 3** Training model. (Source: Own figure)

## 4 Training Model

The didactic method for transmitting the contents is a five-step constructivist training model (Fig. 3) in the tradition of David Kolb's Experiential Learning Cycle [27, 28] which was developed for the special case of didactical trainings at universities [29]:

- The training model starts with the clarification of educational targets, is followed by
- the elicitation of cognitive and emotional prior knowledge,
- the twofold, flexible learning stimulus that consists of a theoretical (instruction based) and a practical (experience based) input,
- the reflection phase involving self-reflection, social reflection and transfer-orientated reflection and ends with
- the transfer of the learned into the participants' individual teaching and action practice in the aftermath of the training (see Fig. 4).

The model is used as a guiding principle for the design and conduction of the whole training as well as single learning episodes. All these phases happen in the group context, so that the seminar can be called a constructivist and collaborative learning context, where the training participants not only benefit from the expertise of the trainers, but also from the experiences and suggestions of their peer colleagues. The training model supports the development of teaching competence by directly developing the participant's personal and social competence and indirectly developing their didactical competences. Their personal competence is fostered by letting the




- **Educational target**: Being able to prevent and solve conflicts
- **Cognitive and emotional prior knowledge**: discussion which conflicts the participants already experienced
- **Learning stimulus**: role play (practical input), discussion how the experienced conflicts can be prevented or handled (interim reflection, social refletion), tipps to handle conflicts (theoretical input)
- **Reflection**: self-reflection, learning journal (transfer-orientated reflection)
- **Transfer**: application of conflict strategies in the actual teaching situation

**Fig. 4** Interaction of content and training model “Handling conflicts with students”

participants reflect on the learned. Through discussions and team work, social competence is promoted as well. With regard to the didactical competences, the training model serves as a role model that indirectly motivates them to clarify educational targets, activate the student’s prior knowledge, to combine practical and theoretical learning possibilities and to have an eye on the transfer of the learned. This helps the participants to develop their teaching competence and to achieve the next step of teaching competence development.

The training begins with the *clarification of the educational targets*. Educational targets define competences that should be attained by the learner at the end of the learning process [35]. The clarification of the educational targets, highlighting the potential gains and benefits of the learning session, eases the learning process because the learners achieve information and are capable to structure their learning. These proclamations are supported by empirical finding that find positive effects on students’ motivation and achievement [36]. The outlining of the educational targets is followed by the next step – the activation of emotional and cognitive prior knowledge.

The *activation of cognitive prior knowledge and emotional knowledge* means that cognitive prior knowledge (previous learned knowledge, skills and abilities) and emotional knowledge (individual experiences and emotions connected with the content) is stimulated and integrated in the training process. This is especially important according to Ausubel [37], who specified that the most important aspect influencing learning is what the learner already knows. This famous statement has been researched and verified in various studies. Hailikari, Katajavuori and Lindblom-Ylanne [38] have found that learner’s previous learning has to be activated in relation to new contents in order to effectively process information, because if this activation is not assured, surface learning can ensue. Besides prior knowledge, another important internal variable moderating the relationship between the intended message and the perceived information, are emotions [39]. By recurring to former experiences, emotions are aroused as well. This is important because when emotions are involved, the brain releases neurotransmitters that mark the event as significant thereby focus attention and facilitate learning [42]. Summing up, by encouraging prior knowledge – achieved through asking questions and discussing the topic – the trainers activating the learner's background knowledge and prepare them for the subsequent learning stimulus accurately.

The *learning stimulus* is understood as a combination of a theoretical (instruction based) or a practical (experience based) input for the training participants. Every learning stimulus consists of a theoretical and practical input, because research has shown that learning is best facilitated when both learning practices are combined [40, 41]. During the theoretical, instruction-based input the trainer provides information to solve typical problems while the participants are actively listening. During the practical input the trainer rather organizes learning environments in which the learners are able to obtain new learning contents actively and autonomously. Research findings and practical experience suggest that different individuals perceive and process experiences in different preferred ways [42]. Accordingly, it is essential to vary the sequence of theoretical and practical input in a flexible manner conferring to the requests of the target group and/or specific topics. If the trainer – on the basis of target group[18] and/or content specifics – chooses to start with the theoretical input, it is followed by the practical part and then leads to the reflection phase. If the trainer starts with the practical input, a short interim reflection is slotted in before the theoretical input is set (see the loop in Fig. 4) [29]. This elaboration by active learning opens up the possibility for reflection and better understanding in the next step.

*Reflection* is the process of (shared) thinking about previous insights and experiences for the purpose of expanding one's opinion and making decisions about improved ways of acting in the future. Three types of reflection are inherent to this definition: self-reflection, social reflection in the group and transfer-orientated reflection. While in the self-reflection phase the learner makes sense of the experienced learning stimuli. After that the learner shares his comprehensions with the group in the social reflection. By paying attention to other participants' insights, the learner deals with the perspectives and (possibly controversial) insights of fellow university teachers. During this social construction process with peers, normative expectations defining the role as "university teacher" are discoursed and illuminated. A special emphasis lies on the transfer-orientated reflection where the learner resolves which

[18] Empirical findings have shown that some group of persons have different learning preferences, e. g. Eschner [43] states that technically orientated individuals tend to favor grasping theoretical knowledge before going to practice.

insights, gathered through learning stimuli, self-reflection and adjusted by social reflection, he plans to transfer into teaching practice [29]. The threefold process of reflection prepares the learner for the aftermath of the actual training situation – the transfer of the learned in every-day teaching practice.

*Transfer* implies the process of integrating and adapting previously learned knowledge and action patterns into professional daily teaching routine. What the participants learned is not realized until the professional teaching situation where the learned is put to the test. The transfer effect of the training is accomplished when the training participants have actually developed their teaching competence and teach student-orientated [44]. The transfer process is facilitated by the use of a learning journal which the participants continually use to write down which ideas they want to put into practice after every learning episode. The multi-faceted process of reflection also motivates the participants to transfer their new knowledge. At the end of the seminar the participants go through their learning journal again and develop strategies how they want to put the ideas into practice. If they identify obstacles regarding the implementation of their ideas, the group helps by suggesting solutions to the problem. In the aftermath of the training, the participants get handouts summarizing the important contents of the training.

After the description of the content structure and the explanation of the didactical framework - the training model consisting of the clarification of the educational targets, the allusion on prior cognitive and emotional knowledge, the learning stimulus, reflection and transfer – the fit of content and model will be exemplarily demonstrated in the following chapter.

## 5 Interaction of Content and Training Model

The fit of the content structure and the didactical model will be illustrated on the following example of the focus: “students”, learning session: “handling conflicts with students”.

The educational targets in the example “handling of conflicts” are an increased awareness of possible strategies to prevent conflicts and to react adequately. The prior cognitive and emotional knowledge regarding “the handling of conflicts” is activated through questioning which possible conflicts the participants can think of and the conflicts they have already experienced in their teaching career. The practical input is a role play scenario in which typical conflict situations are simulated and the participants must try to resolve them. Afterwards, in the interim reflection, the trainers and the group discuss how the conflicts, which have been talked about earlier (activation of prior knowledge), could be prevented or resolved. The theoretical input of the learning session “handling with conflicts” includes the presentation of typical conflict situations in lectures and the corresponding recommendations to solve those conflicts. So it is up to the trainer to decide whether the participants should start with the theoretical presentation of the right behavior in conflict situations and practice them in the role play; or whether the participants should learn from their own experience in the role play which strategies prevent or promote conflicts and then underpin those insights by the theoretical presentation. Referring to the "handling of conflicts" the self-reflection involves the individual realization of what has been learned from the learning stimulus. The learnings concerning the handling of conflicts are discussed in the group context in the social reflection. During the transfer-orientated reflection, the individual decides how he wants to handle conflicts in his teaching practice. In the case of the example "handling of conflicts" the transfer is realized when the training participant accomplishes to solve or even prevent conflicts in his lecture by the use of strategies learned in the training situation.

## 6 Quality Assurance

The quality of the seminar is assured through continuous formative evaluation.[19] At the end of the seminar, the participants are invited to give detailed, qualitative feedback to the trainers. The quantitative evaluation is realized through a standardized, anonymous questionnaire which allows evaluating the seminar objectively over time. In addition to typical aspects of training satisfaction (room, trainer, content, organization etc.), the participants are also asked to make particulars on their actual and former teaching responsibilities, their didactical and teaching experience and the time spent on teaching.

First comments of the participants (**qualitative evaluation**) reveal that the participants appreciate the mixture of theory and practice. Since most of the participants are still in the first development stage (focus on the teacher), they prefer the video feedback. They are often concerned about their teaching performance and in this way they get to know their strengths and weaknesses. It is also recognizable that the less teaching experience the participants have, the more useful they find the seminar.

The standardized questionnaire (**quantitative evaluation**) is still in the pretest phase. First findings are expected to be published in early 2014.

## 7 Summary and Future Prospects

The major goal of the seminar "Academic Teaching" is to establish a starting point for student-orientated teaching through the development of teaching competence. Teaching competence is an abstract concept that has been modeled both bottom-up (normative led) and top-down (evidence led). In the context of ExAcT, teaching

[19] Most instructional design models differentiate between summative and formative evaluation. The primary purpose of formative evaluation is to ameliorate the quality of the program being developed in the ongoing process to assure the objectives for which it was designed will be achieved. In contrast, summative evaluation depicts efforts that assess the effectiveness of completed interventions in order to provide suggestions about their future use [45, p. 952].

competence is understood as the ability to teach student-orientated and is composed of personal competence, social competence and didactical competence, the latter including planning, method, media and evaluation competence.

As the participants' teaching competence evolves with the stages, the content structure of the seminar detects four development stages. As the seminar progresses, the participants wide their scope slowly from their individual perspective towards the students' perspective, starting with the focus on the teacher and following up with focus on content, on didactics and on students and ending with course planning.

The contents are conveyed using the ExAcT training model. Each learning episode starts with the clarification of the educational targets, is followed by the activation of prior cognitive and emotional knowledge, the twofold flexible learning stimulus, the reflection and finalized by the transfer to the professional situation in the aftermath of the training. It is important to acknowledge that all learning involves learning from and with peers, because the participants profit from the experiences of the teachers and have the social experience of talking about teaching with other teaching newcomers.

The seminar arises a basic awareness of the new role as a teacher and teaching competence which is the foundation for further improvement of competence through the participation in other trainings and seminars of the ExAcT qualification program at RWTH Aachen University.

Of course, some challenges still remain – both in practice and research. An important research question is the one of university teacher competence profiles. Though some competence mod-els for university teachers have been published in the last years (e. g. [1, 10–12, 15]), coherent, systematic and empirically tested teaching competence models combining the top-down and bottom-up perspective are lacking. Accordingly, an integrative teaching competence model needs to be theoretically developed, empirically researched and compared with practical teaching competence profiles of university teachers. An integrative point of view is increasingly important, because teaching competence profiles are constantly changing – individually due to personal development processes as well as due to contextual changes and varying teaching competence demands at universities.

The described training model is still in an empirical testing phase, but first findings suggest that the model works for the design and the conduction of the training. Furthermore it will be investigated in detail which group of persons favors which loop of the learning stimulus in order to develop empirically resistant guidelines for the accurate use of the model: e. g. do engineers really like being theoretically instructed before going into practice? Or are economists more open to practical learning than social scientists? For this end a comparative study highlighting the specifics of disciplinary cultures will be conducted. The results of this study will be integrated as concrete training recommendations in the didactical framework of the training model.

The major challenge regarding the practice and research is the issue of transfer and sustainability of trainings. New methods and strategies to ease the transfer of the learned into teaching practice have to be developed and empirically tested. Also the training efficacy and efficiency in general and the individual, social and contextual transfer need to be examined.

In this context, it has to be kept in mind that the motivation of the training participants plays the most important role concerning the transfer. Every university teacher has to come to the conviction how he wants to place himself with regards to his research and teaching duties. It should be the mission statement for centers of didactics to deliver the message that neither the teaching should be neglected to strengthen research nor that research should be abandoned in the favor of teaching. The goal should be research-based teaching in the sense of integrating rather than counterpointing research and teaching. This is especially important because due to demographic developments and structural changes at universities, Germany depends on qualified teaching staff.

## Link List

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Hochschulrahmengesetz. www.gesetze-im-internet.de/hrg/BJNR001850976.html.
ZLW. www.ima-zlw-ifu.rwth-aachen.de/en/institute_cluster/institutes/zlw.html.

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# Intensifying Learner's Experience by Incorporating the Virtual Theatre into Engineering Education

**Daniel Ewert, Katharina Schuster, Daniel Johansson, Daniel Schilberg and Sabina Jeschke**

**Abstract** This work introduces the virtual theatre, a platform allowing free exploration of a virtual environment, as an instrument for engineering education. The virtual theatre features three main user components: a head mounted display, a data glove and an omnidirectional floor. These interfaces for perception, navigation and interaction allow for more realistic and intuitive experiences within environments which are inaccessible in the real world. This paper describes the technical properties of the platform as well as studies on human experiences and behavior. It moreover presents current and future applications within the field of engineering education and discusses the underlying didactic principles.

**Keywords** Virtual Learning Environments · Immersion · Engineering Education

## 1 Introduction

It is a known and well accepted fact that students need practical experience and practical relevance in higher education, especially in engineering. Practical experience is often gained in laboratory work, a widely-used approach to teach the grass roots of science. Experiments are mostly only conducted for basic subjects like physics or chemistry. A common approach to convey practical relevance to engineering students is by offering internships or excursions.

However, because of the costs, complexity and criticality of industrial sites, it is not possible for a student to explore such installments freely and experiment on her or his own, on one hand to ensure ongoing production and to avoid damage to the machines and on the other hand to protect the student from harm by physical forces or contact to hazardous material. Today, there are still few examples in engineering education where practical experience and practical relevance are truly connected to each other.

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To overcome this, it is possible to rebuild such industrial complexes within virtual environments. In simulations or serious games, the principles behind the industrial site are connected with the respective courses. Until now, the drawback of such virtual learning environments is the artificiality of the experience. Usually, the participant interacts with the virtual environment via a pc workstation. The industrial complex is perceived via a computer monitor, and the viewpoint is moved via keyboard and/or mouse. Interactions with the environment are triggered the same way. Thus, the user has to "translate" the control mode of the computer into the actions of his or her graphical representation, the avatar.

To achieve a more natural experience, new interfaces can be used for visualization, navigation and interaction: For high immersion, the participant needs a seamless 3D surround view of the virtual environment. This can be achieved with modern head mounted displays (HMD). For natural navigation, omnidirectional treadmills can be used, which allow free and unlimited movement by tracking the participant's movement and keeping him in a stationary place at the same time. Finally, data gloves allow interacting with the virtual environment intuitively. These described components – HMD, omnidirectional treadmill, and data glove – are incorporated in the so called virtual theatre ([1], Fig. 1).

## 2 Technical Description of the Virtual Theatre

The virtual theatre presents the user with a seamless 3D visualization of a virtual environment. All head movement is instantly reproduced within the simulation, so the user can look around freely. The user can move around within the environment by just walking in the desired direction. Hand gestures can be recognized and allow for manipulation as well as advanced control of the simulation.

### *2.1 Hardware Setup*

#### 2.1.1 Omnidirectional Floor

The omnidirectional floor consists of polygons of rigid rollers, with increasing circumferences and a common origo. Each polygon constitutes 16 rollers and together all polygons form 16 sections with an angle of 22.5°. Each section consists of one roller from each polygon, which means from cylinder origo towards the periphery, the rollers are parallel and increasing in length. Rollers are driven from below by a belt drive assembly to minimize distance between sections. In the central part of the floor there is a circular static area where the user can move without enabling the floor. Floor movements here would only cause the feet of the user to be drawn together. As the user moves outside the static boundary, the floor begins to move according to a control algorithm (Fig. 2).

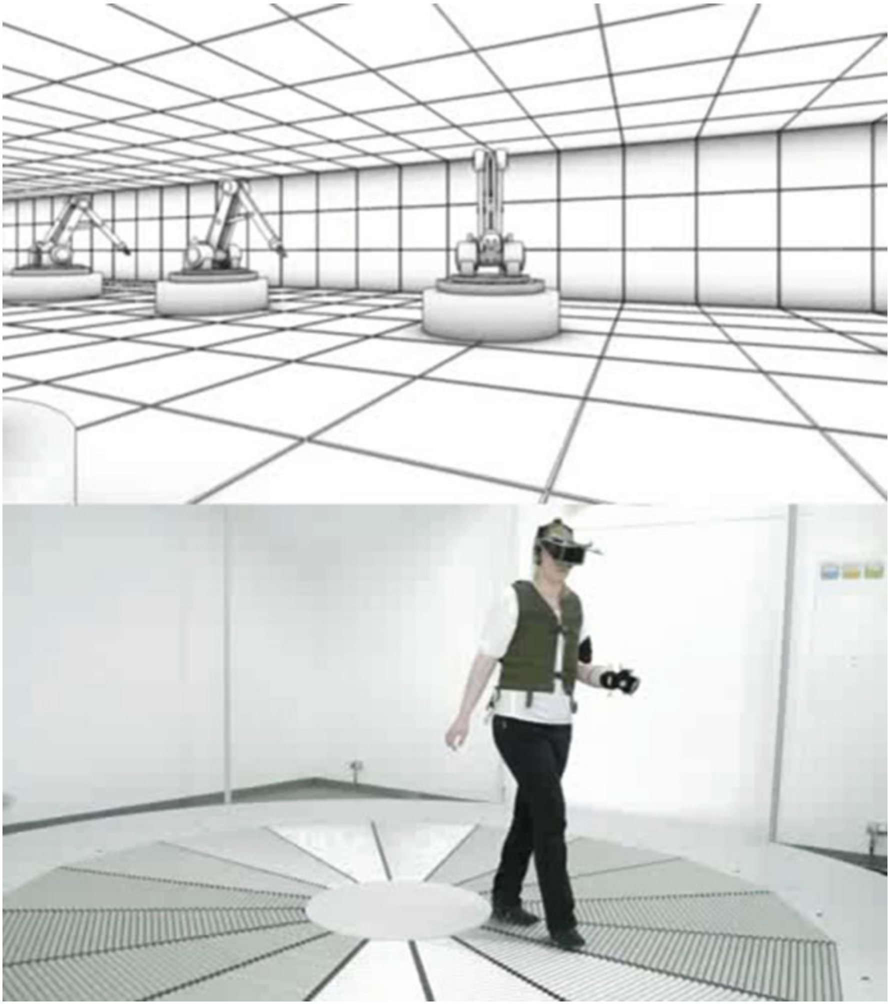

**Fig. 1** Virtual theatre with user and (simplified) virtual environment

**Fig. 2** CAD model of the omnidirectional floor

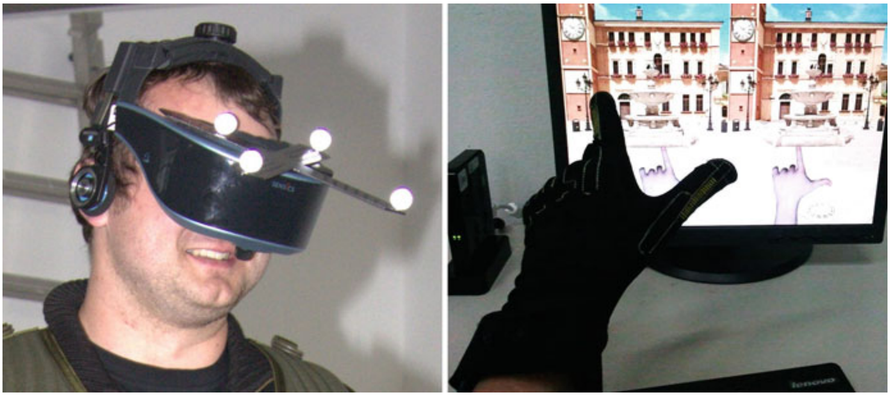


**Fig. 3** Head mounted display with attached infrared markers (*left*); Data glove and representation in a virtual environment (*right*)

### 2.1.2 Head Mounted Display

Visual and auditory feedback is received via a zSight [2] head mounted display, providing a 70° stereoscopic field of view with SXGA resolution for each eye, and stereo sound via attached head speakers (see Fig. 3) The HMD weighs 450 g.

### 2.1.3 Data Glove

To interact with the virtual scenario, a user can utilize hand gestures. These are received by 22 sensors incorporated in a data glove [3]. Currently, only one data glove is incorporated in the virtual theatre, since the added value of a second would glove would be minimal (you can lift and move every virtual object single-handed), while object manipulation and two handed gesture detection would become unnecessarily complex. However, later incorporation of a second glove is generally possible.

### 2.1.4 Tracking System

To track the movements of a user, the virtual theatre is equipped with 10 infrared cameras. They record the position of designated infrared markers attached to the HMD and the data glove. The position of the HMD serves on the one hand as an input for controlling the omnidirectional floor: The inward speed of the rollers increases linearly with the measured distance of the HMD to the floor center. On the other hand it is used to direct the position and line of vision of the user within the virtual environment. The position of the glove serves for representing the hand within the virtual environment and for triggering emergency shutdown: As soon as the hand drops below 0.5 m, e. g. in the unlikely event of a user falling down, all movement of the omnidirectional floor is immediately stopped.

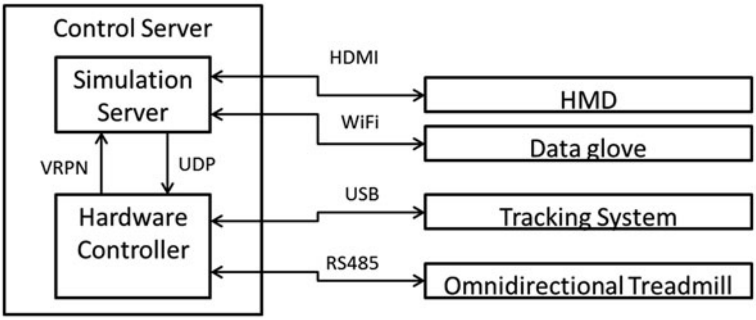


**Fig. 4** System architecture of the virtual theatre

### 2.1.5 Integration of the Components

The system architecture of the virtual theatre is depicted in Fig. 4. The fixed components tracking system and omnidirectional floor communicate to a hardware controller via cable-based communication channels. However, to allow for unconstrained movement, all hardware that is worn by the user communicates wirelessly.

## *2.2 Software Setup*

The theatre's server consists of two personal computers serving different purposes. The hardware control server analyzes the data from the infrared cameras and regulates the omnidirectional floor. For tracking the user's movement it uses Optitrack Tracing Tools [4]. The position information as well as the velocity of the floor is sent to the simulation server via vrpn [5], a device-independent and network-transparent interface to virtual reality peripherals. The simulation server is responsible for high level control and provides the virtual environment. Therefore it makes use of the Vizard Virtual Reality Toolkit [6]. 3D Models for virtual environments are generated with blender [7] and can be loaded into Vizard.

## *2.3 Limitations*

Currently the only provided feedback to the user is visual or auditive. Other feedback sources in form of heat or air draft are generally possible but not yet part of the current installation or scenarios. Due to the single center of the treadmill where the user is held, the virtual theatre allows for only one operator. Further spectators can follow the operator's actions on additional screens, but cannot interact directly with the virtual environment.

However, cooperative scenarios, where spectators instruct the user, assist in other ways, or even accompany the user as virtual classically controlled avatars are possible. Nevertheless, the virtual theatre is only applicable for small groups of students. This needs to be kept in mind when a didactical method for the respective courses in engineering education is chosen. An interesting research question is if the students who have the observer perspective also have a learning experience as the theory of observational learning of Albert Bandura [8] suggests.

## 3 Human Experiences and Behaviour

### *3.1 Concepual Background of Immersion*

In general, all interfaces of simulators have the purpose to create a perfect illusion for the user that he or she actually feels as being in the simulation. Before the virtual theatre is going to be used within engineering education, a better insight in the students' perception of the learning situation and of the learning outcome is needed. Therefore the further development of the hardware and of the scenarios is attended by different psychological studies. Before the experimental design of the studies is explained in detail, a closer look at the conceptual background of the notion of immersion is needed, which appears very often in the context of the work towards more realistic simulators.

The term immersion is frequently used as an objective, gradable measurement to describe how capable technical features are to create perfect illusions. A head mounted display for example is considered a good device to create immersion. Moreover, an HMD which provides the user with a 101° view is more immersive than a display which only provides 100°. Regarding the virtual theatre, a simulator which provides unrestricted movement has a higher grade of immersion than a simulator which doesn't have this characteristic [9].

In gaming circles, the term is used by gamers in order to explain to what extent a game can draw them in and allows them to "lose" themselves in the world of the game. Reading through forums and blogs, it also becomes obvious that within the gaming community, the meaning of immersion is ambiguous and multifaceted, from the ability of a game to "pull you away from your actual world, and swamp you with an actual psychological experience full of emotional turmoil and conflict [10] to "a games ability to draw you in with elements OTHER than it's (sic!) characters and story" [11].

Either way, immersion has a positive connotation and is a quality seal for computer games. Considering the hardware, new interfaces like Nintendo Wii or Kinect for the Xbox console illustrate the craving for more natural control modes in the entertainment sector. However, although there seems to be a broad understanding of immersion amongst hardware developers and in the gaming community, it is still not clear what exactly is meant by immersion and what is causing it from a psychological point of view, especially if the goal is not only entertainment but learning.

In a first general approximation, immersion can be defined as "the subjective impression that one is participating in a comprehensive, realistic experience" [12]. The idea of absorbing and engaging experiences is not a new concept and there are several other concepts that have a relation to immersion. Involvement, spatial presence and flow are considered key concepts to explain such immersive experiences, although they are not clearly distinct and depending on the author overlap and also refer to each other. Involvement is a psychological state experienced as a consequence of focusing one's energy and attention on a coherent set of stimuli, activities or events and it depends on the degree of significance or meaning that the individual attaches to them [13].

Whilst flow describes the involvement in an activity, presence refers to the spatial sense in a mediated environment [14]. Rheinberg et al.'s concept of flow in human-computer-interactions consists of the two subdimensions (1) smooth and automatic running and (2) absorption. The first factor refers to the feeling of utmost concentration and focusing, control over the activity, clarity of the operations, and smooth and automatic cogitations. The second factor refers to the feeling of full involvement, distorted sense of time, optimal challenge, and absent mindedness [15].

It has been shown in many studies that personal characteristics have an influence on immersion. Immersive tendency describes the ability of a person to focus on an activity and to lose track of time and space [13]. Weibel et al. [14] showed that openness to experience, neuroticism, and extraversion of the Big Five personality traits are positively correlated to the tendency to be immersed.

Another personal characteristic that is expected to have an effect on a person's experience in a virtual environment (VE) is affinity for technology. Since the virtual theatre is a very new and innovative technology it is also expected to lead to higher enjoyment during task performance than a laptop if the person generally likes technology. Especially in a simulator which enables free movement like the virtual theatre, cognitive skills like spatial sense might also have an effect on a person's experience but also on his or her performance.

## *3.2 Experiment Design*

The studies on human experience and behaviour in the virtual theatre assess the subjective experience of presence and flow (experience) as well as learning outcome (behaviour). In line with Witmer and Singer [13] the studies carried out in the virtual theatre follow the approach that the strength of presence and flow experienced in a VE varies both as a function of individual differences and the characteristics of the VE as well as the hardware of the simulator. Individual differences, traits, and abilities may enhance or detract from presence and flow experienced in a given VE. Various characteristics of the VE and of the hardware of the simulator may also support and enhance, or detract and interfere with the subjective experience in the learning situation.

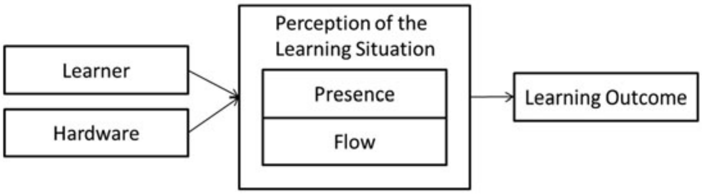


**Fig. 5** Expected relationship between learner, hardware, perception of the situation and learning outcome

Hence, the measures assess individual differences as well as characteristics of the VE and of the virtual theatre that may affect presence, flow and enjoyment. One of the most important questions within an educational framework is whether experiencing a VE via a virtual theatre leads to better learning outcomes than e. g. experiencing a VE via a laptop or just an HMD. Therefore the last step of the studies is knowledge retrieval. The expected relationship between learner, hardware, perception of the situation and learning outcome is visualized in Fig. 5.

To measure the strength of the effect of each variable, different study designs will be carried out within the virtual theatre. A first study will measure the immersive quality of the virtual theatre as well as its ability to improve learning. Therefore two groups of students will be compared in a first study, having to use different hardware (independent variable) in the learning situation. The variables virtual environment (a maze) and task (finding different objects in the maze) will be kept constant. The treatment group will have to fulfill the task in the virtual theatre and the control group on a laptop. The retrieval task will also be kept constant for both groups (locating the objects on a map of the empty maze on a tablet pc). Measures will assess the subjects' perception of the learning situation and the accuracy of the location of the objects.

A second study will focus of the immersive quality especially of the omnidirectional floor. Therefore two groups will have to fulfill the same task (looking around freely) in the virtual theatre, in the same virtual environment (Italian piazza). While the treatment group will have to perform physical activity (walking) within the virtual theatre, the control group will only have to make use of the 3D view (independent variable = physical activity). The retrieval task will be the same as in study one (locating the objects on a map of the piazza on a tablet pc). Measures will again assess the subjects' perception of the learning situation and the accuracy of the location of the objects. With a constant validation of the relation between student, hardware and learning outcome, it is possible to predict the level of immersion in the virtual theatre from personality. Thus, a profile could be developed, for which students the virtual theatre would have the best effect and would be most suitable. Moreover, different scenarios could be developed for different profiles.

Further studies on human experiences and behavior in the virtual theatre will include the scenarios developed for engineering education, which are described in the following chapter.

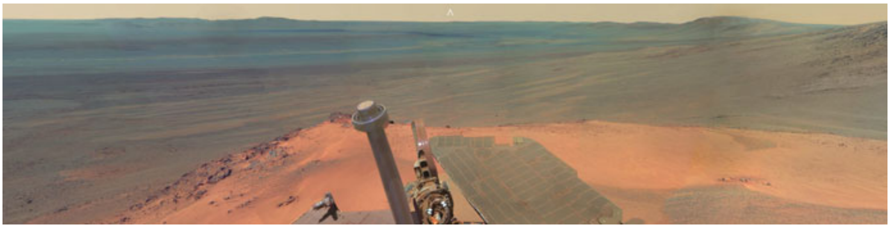

**Fig. 6** Panoramic view taken from the Mars rover (property of NASA)

## 4 Application Scenarios

The virtual theatre offers a lot of possibilities for different application areas. Theoretic background knowledge can immediately be verified in a practical and perceptible way, especially for in reality not accessible situations. At the Institute for Information Management in Mechanical Engineering the virtual theatre will be used for Engineering Education and as part of a school lab of the German Aerospace Center (Forschungszentrum der Bundesrepublik Deutschland für Luft- und Raumfahrt, DLR). The scenarios developed therefore cover the areas of power plants, production facilities, facility planning or space travel. Different target groups are integrated actively in the development of new scenarios. Following the lead user approach [16] different workshops with students and teaching staff are carried out. Their ideas for scenarios and didactical approaches melt into the activities of the research group in charge. After two scenarios are being presented exemplarily, the underlying didactical principles are explained.

### *4.1 Scenario 1: Mars Mission*

The first scenario in development is a Mars scenario where the user can walk on the surface of planet Mars. It consists of a reproduction of the landing area of the rover spirit, based on a height map of the landing are and high-definition pictures of the Mars mission. Within this environment, exact models of the different Mars rovers are placed. Based on the position and point of view of the users, additional information is presented through pop-up labels (Figs. 6 and 7).

### *4.2 Scenario 2: Nuclear Power Plant*

A second scenario to be developed simulates a nuclear power plant. Students are going to be able to inspect the inner structure of a nuclear reactor and experiment freely within. Conceivable interactions would be to allow for direct manipulation of

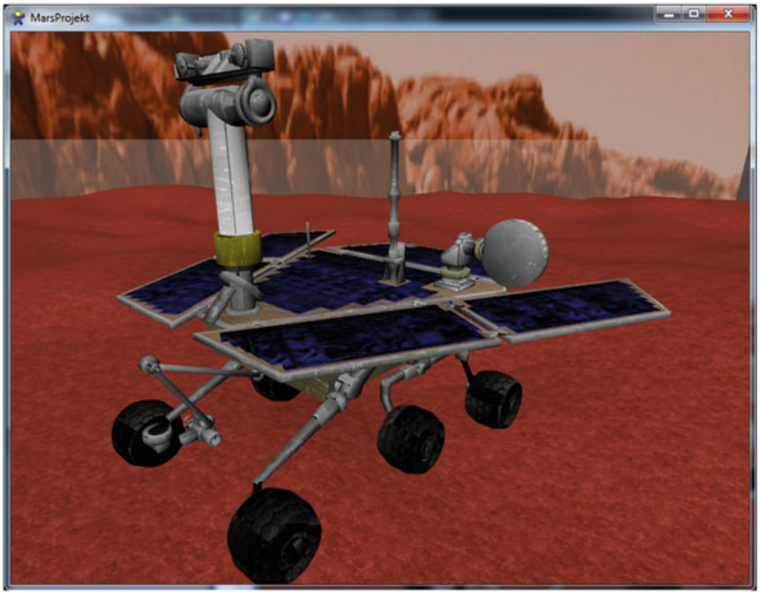


**Fig. 7** Model of the Mars rover opportunity (property of NASA)

the fuel and control rods as well as cooling, etc. The consequence of every action is immediately shown in the virtual environment along with the underlying equations. Additionally the varying noise of a contamination meter indicates radiation levels (Fig. 8).

## *4.3 Didactical Principles*

The content of a certain engineering topic does not transfer itself to the students just by presentation. It has to be prepared with a didactical method in order to actively encourage learning processes. Moreover, one must always keep in mind that students not go to university in order to learn content and to accumulate knowledge, but to develop competencies. In both scenarios, different didactical methods and principles come into operation. The fact, that the students can apply theoretical knowledge in practical situations in a computer simulation supported by the repetition of the theory in the pop-ups helps them to sustainably anchor the knowledge to experiences and maybe stories instead of just memorize facts.

Another method which comes into action within the virtual theatre is exploratory learning, where content is not presented sequentially like in a lecture but openly. The main principle is that the learning process is controlled by the students. This offers the chance to activate their interest and also appeals to their motive of curiosity. As a consequence, the students set their own goals (the want to know or be able to

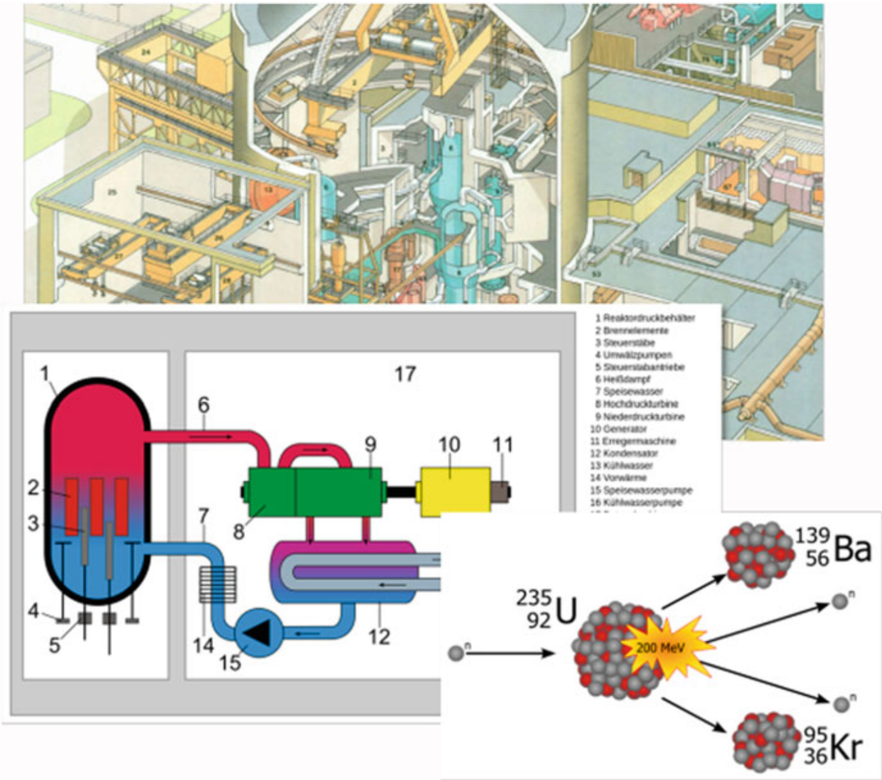


**Fig. 8** Schemas of a nuclear power plant

do something) and they choose the activities which are necessary in order to reach those goals. Therefore in exploratory learning environments, learning is a non-linear process. Students can walk into dead ends, come back, and repeat certain steps etc. in order to move forward. Self-controlled learning processes are an important premise for students to develop employability, as e. g. demanded in the Bologna Declaration [17].

But there are also inhibiting factors for exploratory learning which have to be considered when putting up a new virtual learning environment. Every student has his or her own subjective mental model of the concept of learning. Vermunt and van Rijswijk [18] analyzed those subjective theories about learning of students and found three different concepts. Within the most common concept (reproductive learning), learning is being understood as a process of copying spoken or written word into the memory. Another subjective theory of learning focuses on the use of knowledge: Here, learning is a needed process, in order to be able to reproduce something subsequently at other times. Within the third concept, which happens rather rarely, learning is the necessity of self-contained examination and construction of knowledge. If students have the subjective theory of learning being a process of copying instead of self-contained construction of knowledge, they mostly also believe that in order to learn something, they need to be instructed properly by an expert [19]. The consequence for the virtual theatre is that the application scenarios need to be adaptable to the different subjective mental models of learning. This could easily be included in the development of scenarios for the virtual theatre by scaling up and down the amount of explicit knowledge repetition in pop-ups or some kind of guiding voice in the background.

In general, computer simulations offer the possibility to change the perspective and therefore making otherwise inaccessible situations accessible to the students. In a future scenario with industrial facilities, the student could take the role of the product in a production machinery in order to fully understand the principle of a value-added process. Other application areas of the same principle are the journey of a container box in logistic processes or a journey through the human body from the perspective of a blood cell, like in the TV series *Once upon a Time... Life* [20].

A promising approach which came up in a workshop with students is game based learning (GBL). The biggest advantage is here that playing or gaming is usually a voluntary activity and not carried out for learning purposes. Nevertheless, through games we learn to deal with quit complex scenarios, like chess [18]. For the virtual theatre, there are different possibilities to turn the developed scenarios into games. First, the student can be given a certain mission which has to be fulfilled or a problem that has to be solved. The student then tries to solve that problem or fulfill the mission with his own skills and knowledge (implicit learning). Only when students can't proceed, they can switch to an explicit mode, where additional information is given to them. This switch can be an inhibiting factor on perceived immersion, so those effects still have to be investigated. Another possibility is to imply different levels to a game or a VE. In an industrial scenario, students first would have to handle a simplified machinery in order to understand its basic principles and then move forward to more complex situations, where certain parts of the machinery get broken and they have to repair the site.

## 5 Conclusion and Outlook

In this work we introduced the virtual theatre as a new tool for exploratory learning within virtual environments. We described the technical implementation and integration of the hardware as well as the software components. We presented first applications and discussed the impact of increased immersion on the learning situation. Future application scenarios will focus an industrial facilities and machinery. It is considered to combine the virtual theatre with remote laboratories, so that the users movements within the VE are mapped to robotic manipulators. The result of the latter actions are then fed back into the VE and displayed accordingly. First applications here will be based on test benches for metal bending.

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# Enabling Innovation in Engineering Education by Providing Flexible Funds for Teaching Staff

**Nina Friese, Claudius Terkowsky, Dominik May, A. Erman Tekkaya, Katharina Schuster, Anja Richert and Sabina Jeschke**

**Abstract** High quality Engineering Education is the key to master the challenges of tomorrow. Universities need to adjust their curricula to current requirements to overcome the global shortage of engineers. TeachING-LearnING.EU supports them in identifying and achieving the necessary steps. The subject center for higher engineering education was founded in 2010 by the three universities RWTH Aachen University, Ruhr University Bochum and TU Dortmund University. Right from the start TeachING-LearnING.EU implemented a funding concept which allows engineering teaching staff to apply for financial support to implement innovative teaching ideas. Each semester, there is a call for ideas. The ideas are evaluated by TeachING-LearnING.EU, and the best applicants receive a funding of up to 30.000 EUR over a period of 1 year. The money can only be invested in staff costs. By the end of April 2012, 22 innovative teaching projects will have been supported by the Flexible Fund Program.

There is investment and benefit for all involved parties. Chairs and Institutes, whose staff receives funding, still need to invest manpower and additional money as the funding regularly does not cover 100 % of cost. In addition to financial funding they benefit from competent consulting and sustained improvements in teaching and learning strategies. TeachING-LearnING.EU invests money in funding but the Subject Center's central goal goes beyond financial support: They give the faculties' teaching staff help and advice in didactical questions and – this is the main point – scientifically evaluate the funded ideas. This makes a central contribution to scholarship of teaching within TeachING-LearnING.EU's sphere of activity.

The evaluation concept focuses on the impact the funded ideas have on teaching and learning in engineering education, Evaluation und Qualitätsentwicklung. Eine Grundlage für wirkungsorientiertes Qualitätsmanagement, Waxmann, Münster). It has three target levels: On the highest level the ideas are evaluated with regards to their contribution to the general goals of TeachING-LearnING.EU, e. g. implementing the shift from teacher centered to student centered courses. On the second level

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evaluation focuses on the aims of the Flexible Funds concept, e. g. increasing the teaching staff's motivation to experiment with new approaches in teaching. On the most detailed level the ideas are evaluated with regards to their explicit goals and if these are reached.

In the full paper we will explain the evaluation concept and process in detail. We will present first evaluation results and give insight in funded ideas and illustrate their results.

**Keywords** Innovative Engineering Education · Funding Concept · Evaluation Concept

## 1 Introduction

The working world has changed significantly for young engineers in the course of recent decades. Globalizations of production, increasing diversification of products, shorter product life cycles and greater complexity of technical products are just a few examples of the challenges of our time. This changing environment demands new competencies from engineering graduates. Excellent technical knowledge clearly is one of the most important requirements to be a good engineer. But also the ability to think creatively in complex situations, to communicate adequately about engineering-related problems to different kinds of target group and responsible acting in international and intercultural contexts are crucial competencies for the engineers of tomorrow. It is clearly not enough to sum up those qualities under the headline of "professional experience". It cannot just be the task of companies and industry to train their staff in those non-technical skills. Universities themselves must foster the development of those aforementioned key skills.

In 2010, the initiative of the Mercator and Volkswagen Foundations "Bologna – The Future of Teaching" funded degree programmes and competence centres for different fields in Germany based on the example of UK Subject Centres. In order to adress the challenges in engineering sciences emerging from the Bologna Process, three prestigious German Universities of Technology, RWTH Aachen University, Ruhr-University Bochum and TU Dortmund University launched the Competence and Service Centre for Teaching and Learning in Engineering Sciences: TeachING-LearnING.EU. It provides universities with adequate approaches, concepts and methods on their way towards excellent engineering education. Research, service and strategic networking are the key elements of TeachING-LearnING.EU (see Fig. 1). Various, in parts customised, measures come into operation.

In the daily work of TeachING-LearnING.EU the three key elements are closely interconnected. Experience of teaching staff shared in workshops form the basis for new research questions and vice versa. The main goals of Teaching-LearnING.EU are closely linked to the TeachING-LearnING.EU mission statements and can be summed up as follows [1]:

- to adjust engineering education to competences and learning outcomes,
- to develop a sensitivity for increasing diversity amongst students,

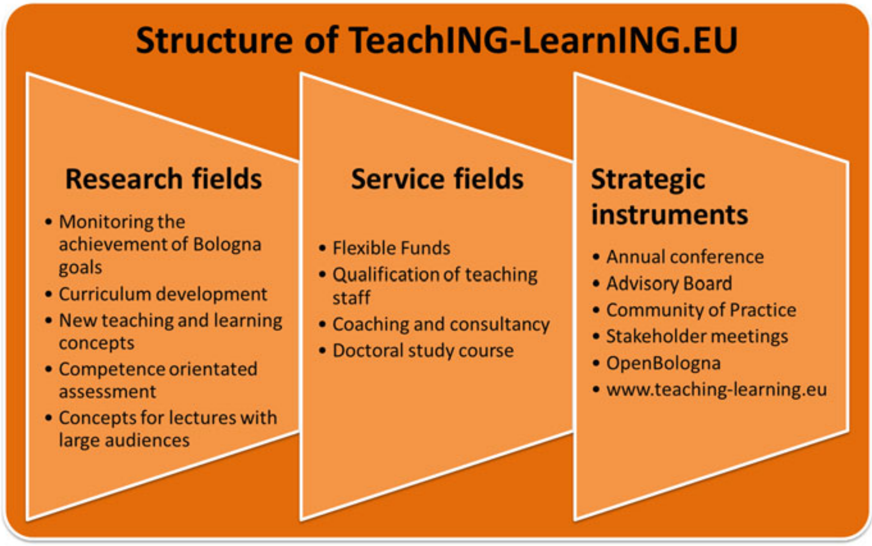


**Fig. 1** TeachING-LearnING.EU key elements

- to preserve a high scientific standard of degree courses,
- to shift from teaching to learning,
- to improve study conditions,
- to lower the drop-out rate,
- to intensify dialogue between students and teaching staff, and
- to adjust teaching methods to the expectations of digital natives [2, 3]

Special attention is given to the integration and participation of teaching staff in the improvement of teaching and learning. With *Flexible Funds*, a special programme was developed, by which teaching staff members are given financial and didactical support, should they wish to implement new teaching concepts. This measure for bringing teaching innovations to engineering faculties is described in more detail below. As this research is in progress and we are right in the middle of the *Flexible Funds* programme - at the end of the first funding phase and at the beginning of a second one – this paper does not as yet present any final detailed results. Instead, it explains the general idea of the *Flexible Funds* programme, followed by the concept for the programme's evaluation. The paper closes with an outline of the first results from the past funding phase, and an outlook of future work in this context.

## 2 Flexible Funds

In many universities highly engaged teachers improve their classes continuously. Little changes like a video during a speech or starting a discussion with the students can already have an impact. Apart from individual commitment, many universities strategically provide funds and measures to improve teaching so new concepts can be tried out where the absence of time and money would have otherwise prevented it. Especially if the development of competencies is intended, a strong linkage of technical know-how and soft skills is important. A teaching concept which fulfills those requirements can only be developed by the teacher him- or herself. The challenge these teachers often face is a lack of money and/or time to implement their new ideas. In order to support these teacher's motivations to improve their courses, TeachING-LearnING.EU developed a programme called *Flexible Funds* and releases a call for proposals every year. Teaching staff can apply for personnel costs up to 30.000 €. The sum of money is not very high but should be understood as a first incentive for change. Therefore the bureaucratic hurdle is set very low. The applicants have to fill out a mask of only three pages, which contains the key aspects of the teaching innovation, the quality goals, a didactical concept and the schedule. The *Flexible Funds* enable members of the teaching staff to redesign their teaching methods and to try out new ideas. The financial support also helps them to overcome possible "invisible barriers" within their own institution, e. g. a culture where optimising teaching concepts doesn't have a high priority compared to research.

Forty-five applications for a fund have already reached TeachING-LearnING.EU within the *Flexible Funds* programme since 2010. All in all 22 projects are finally being supported at the three participating universities. The TeachING-Learning.EU team selected the best projects with strong support from external experts and a student council team. The selection followed the criteria "novelty of the teaching or learning concept", "sustainable implementation of the concept within the curriculum", "interdisciplinary unions" and "range of affected students".

The approach behind the *Flexible Funds* programme goes beyond financial support and fostering dialogue about innovative teaching amongst the staff members. TeachING-LearnING.EU accompanies each project, counsels if necessary and helps with the evaluation process. From a meta-perspective, the whole *Flexible Funds* programme is being evaluated regarding its effectiveness and impact.

## 3 Scientific Support and Evaluation of the Flexible Funds Projects

The evaluation of *Flexible Funds* projects follows two fundamental criteria. On the one hand it is important to evaluate the effects of each project and find results of tangible changes in the teaching concept to gain knowledge of its further development and improvement. On the other hand it is necessary to examine and evaluate the effects under the aspect of how a funding instrument such as *Flexible Funds* can serve to improve teaching. To achieve both criteria TeachING-LearnING.EU tries to include all participants in the process of evaluation.

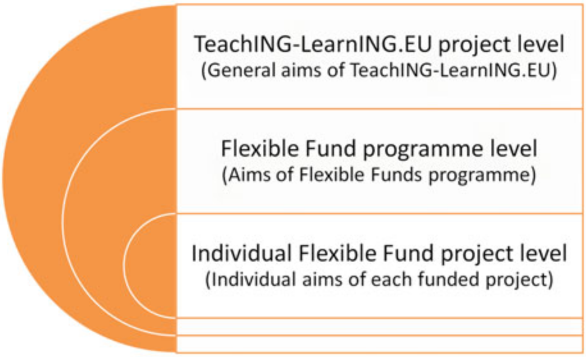


**Fig. 2** Three levels for projects' evaluation

### *3.1 Effect Orientation as a Basis for the Evaluation Process on Three Levels*

As a theoretical framework for the Flexible Funds evaluation process we use the effect-orientated evaluation concept [4, 5]. Effects occur as changes of structures, processes and/or individual behaviour. They can be subdivided into the ones intended and in compliance with the aims of a programme or into the ones not intended. The effect-orientated evaluation concept attempts to track all the initiated effects of a programme or method and does not primarily consider only the intended ones. The task of scientific support and evaluation therefore is – and that is what TeachING-LearnING.EU does - to describe, analyse and possibly clarify intended as well as unintended effects [6].

Within the Flexible Funds evaluation process we divide three interconnected target levels of effects (see Fig. 2):

These three levels are designed with respect to the general aims of the TeachING-LearnING.EU Competence and Service Center (first level), the aims of the *Flexible Funds* programme (second level) and the objectives every single *Flexible Funds* project has in its specific context (third level). In the following we will outline the different aspects every level addresses:

1. TeachING-LearnING.EU level: On this level the evaluation process focuses on whether the *Flexible Funds* projects meet the general goals of TeachING-LearnING.EU as stated above.
   – understands competences as the intended learning outcomes,
   – considers adequately the increasing diversity among students,
   – saves the scientific quality of the course,
   – focuses on the learners within the teaching and learning process and supports the shift from teaching to learning,

- improves the study conditions in general with special regard to the alignment of learning outcomes, learning activities and assessment as well as from organizational point of view,
- helps to decrease the quit rate in engineering studies,
- intensifies the communication and interaction between the teachers and the students, and
- adjusts teaching methods to the needs of the digital natives.

2. *Flexible Funds* programme level: The programme itself follows specific targets. Therefore on this mid-level the evaluation process analyses if the *Flexible Funds* project meets the criteria stated above. Moreover it is being evaluated if the project
   - fosters teaching innovations,
   - cares for a sustainability change in teaching method,
   - initiates interdisciplinary unions in teaching,
   - increases the motivation of teaching staff to plan, perform and evaluate self-initiated, innovative courses, and
   - has a positive influence on the self-perception of the teaching staff regarding its options in designing and implementing new course concepts in teaching.

3. Individual *Flexible Funds* project level: This level takes a look at each promoted project and its specific approach to improve the teaching and learning process within the context of their faculty. It is difficult to outline specific aims because every project has its own context and objectives. To give a feeling how these aims were defined we show three different project aims as an example. On the most detailed level the evaluation process analyses if the *Flexible Funds* projects reached their aims. For example the aims of:
   - successfully implement problem based learning in existing course concept in order to increase technical understanding as well as the key competences (e. g. the ability to work in teams) among the students [7],
   - increase leadership skills among the PhD students by implementing a special coaching concept [8], or
   - connect theoretic background of business cybernetics with realistic experiences by implementing a simulation in the course [9].

## 3.2 Practical Steps within the Evaluation Process

The innovation cycle and evaluation process of the first *Flexible Funds* round started in March 2011. In order to get a broad overview of the projects as well as a detailed view into the projects' progress all three parties - teaching staff, students and TeachING-LearnING.EU team – were involved in the evaluation process. For all three groups we have chosen special instruments for the evaluation process in order to address their specific needs.

1. For the students open as well as closed questioners were used during the evaluation process. In small courses also group discussions were used. This was done in order to obtain different facets of the three research levels.
2. For the teaching staff and other involved project members mainly guideline supported discussions and interviews were applied before, during and after the project. This helped to register the individual project members' perspectives on the projects' progress and encouraged at the same time a reflexion of successful and difficult aspects of the project [10].
3. Participatory observation was the third fundamental evaluation instrument. During the one year funding phase members of the TeachING-LearnING.EU team visited each project at least once. This insight helped to get a deep understanding of the procedure of a new teaching concept and its implementation. At the same time the team will be able to support the teaching staff immediately if any questions or problems arise.

## 4 Observations of the First Evaluation

After explaining the evaluation process of the *Flexible Funds* programme we now want to focus on the first results. The following chapter is divided into two main parts: the evaluation by teaching staff and TeachING-LearnING.EU followed by the evaluation of the projects from the students' perspective. The reason for combining the first two perspectives is the close cooperation between the teaching staff and the TeachING-LearnING.EU team members. Hence, separating these two perspectives would have been artificial.

### *4.1 Project Evaluation by Teaching Staff and TeachING-LearnING.EU*

All the projects funded by *Flexible Funds* implemented new and innovative teaching and learning concepts, almost in the way it had been planned in the project submission. The preliminary results of analysing the material, observations, documents and discussions connected to the first call of *Flexible Funds*, are as follows:

- It has been extracted from the semi-standardised interviews that financial support makes planning and implementing new teaching projects much easier. In some cases, the *Flexible Funds* programme even functioned as an initiator of new teaching projects. The financial support moreover motivated the members of the teaching staff to refine their teaching concepts.
- It is not only the amount of money that leads to the participation on the *Flexible Funds* call of proposals. The appreciation of teaching is also decisive.
- The teaching staff almost entirely stated that the process to change the course is enriching for the teaching concept, yet strenuous. They are very satisfied with the

learning results of the students and the success of the own project. However the implementation of a new teaching concept may mean more work and uncertainty of success.

- Feedback conversations with teaching staff showed a positive view of student-centred teaching and learning formats. This view was often strengthened during project implementation. Once the teachers realised the benefit for the students in student-oriented teaching methods they continued the project even more motivated.
- In most of the projects the course changed from a classical lecture to group-work, which meant more active work for the students during the course. Study in this manner is different from the general learning culture in engineering courses in Germany. Not all students liked the change. Some negative reactions confused the teaching staff. Appreciation is crucial for teachers' motivation to modify their courses.
- The involved staff stated that the desired sustainability of the funded projects is given. However the sustainability depends on the corresponding people and the resources involved. Moreover, they said that projects would probably only be run beyond the funding phase if the teacher stayed at the faculty and he or she is motivated from the experiences made during the funding phase. It also depends on the individual circumstances, such as support of the faculty dean, the professor or colleagues. In some projects, sustainability also depends on further financial support.
- The participatory observation of teaching and learning sequences by the TeachING-LearnING.EU team was perceived in different ways. Staff members used the visits of the team for the exchange of didactical aspects or to get feedback on their performance. Sometimes however the visits were perceived as uncomfortable and as a control mechanism.

Summing up the teaching staff's feedback it can be stated, that the people involved in the projects are satisfied with the results of the pilot phase. The potential and the positive influence of *Flexible Funds* also become clear in the great number of repeat applications for the second call.

### 4.2 Student Evaluation of the Project

The feedback from the students on the group-work or project-work in the different projects was mainly positive. In many cases they noticed an advantage in the changed course concepts. For themselves they recognised that they learned more as a result of the new concepts than it would have been the case in a classical lecture. They especially see the combination between studying factual knowledge and applying it within a narrow time frame as helpful for a deep learning approach. The mostly student-centred and activating new course concepts offer intensive interaction between teacher and students amongst students themselves. This is welcomed by the students. Additionally, students perceived a development in different soft skills like self management, communication skills and ability to work in a team. The enjoyment of working on realistic challenges in the engineering field motivated students.

Apart from many positive reactions from the evaluation, some students also criticised some aspects of the projects. For example if the phases of discussions are very long or the teamwork doesn't work well some students fear not gaining enough knowledge to finally pass the examination. The students of engineering in Germany are used to taking in a lot of factual knowledge in a short time and to reproduce this in the examination. After the first 2 years of studying most of the students are deeply rooted within the culture of their study field, which means that many German engineering students sit in the lecture hall and listen to the teachers' lecture. Since in engineering education (at least in the first 2 years of study in Germany) an attitude of passive listening and maybe taking notes is cultivated active approaches mean radical change for the students. This partly results in a rejection of active approaches. In interviews with the students some stated to be overwhelmed with the new student-oriented concepts at first and therefore shunned participation. This may lead to confusion between teachers, who wanted to change the course concept into a more student-centred one and students, who wanted to keep the classical lecture. That led to a special effect: The discussion between all people concerned by the new course concepts had the effect, that changes in the understanding of one's role were initiated. Whereas the teachers in many cases more and more understood the students as a valuable party during the course design, the students perceived themselves as an active part during the course design process and the course itself. Hence many teachers openly asked the students to help with the improvement of the teaching concepts and they added productive ideas for the optimisation and gave constructive feedback to the evaluation process.

## 5 Conclusion and Outlook

From these first observations we extracted many results and aspects for the new funding phase. Basically all the projects successfully introduced new and mostly student-centred teaching concepts in their courses. Teaching staff showed a high motivation for these changes and realised that depending on the intended learning outcomes group-work or project-work have advantages in comparison to classical lectures. The team of TeachING LearnING.EU will henceforth encourage the staff members to develop evaluation criteria in a manner that students see themselves as co-creators of new teaching environments and have that role in mind when they give feedback.

It can be stated that the students' and the teaching staff's feedback addressed all three levels of evaluation. Only to one aim on the Flexible Fonds programme evaluation level there is no result. In this phase we can't say whether interdisciplinary unions were initiated.

Over all, the results show that we are on the right track in supporting the shift from teaching to learning in engineering education from all points of view. Especially the students approved in the new course concepts a high relation to practical application, a coherent connection of theory and practice, the intensive dialogue between teaching staff and students, and working autonomously on different topics with their teams.

For the future possibilities of keeping up the didactical support for the projects even after the period of financial funding need to be considered. This would help to coach the teaching staff more intensively and to support them in keeping up their good work. A future alternative to the financial support would be to provide a different kind of long-term support, such as coaching or workshops on a frequent basis and on relevant topics. Additionally, the moderation and advisory service of TeachING-LearnING.EU as external experts will stay useful for the staff. In order to develop a system of self-renewing study courses (learning curricula) it remains to be seen whether the instrument Flexible Funds should be maintained within the faculty's budget in the future. Thus, a long-term and sustainable incentive for the improvement of teaching could be provided. It will be interesting for TeachING-LearnING.EU to evaluate how strong the impact of the previously funded projects is going to be within their faculty. The goal of triggering a snowball effect could be verified in cycles with short interviews with the former participants on an annual basis.

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# Mapping the Goals of the Bologna Process

**Alexander an Haack, Laura Braun, Ursula Bach, René Vossen and Sabina Jeschke**

**Abstract** The ratification of the Bologna Process in 1999 has led to fundamental changes in the European higher education area. After more than a decade of Bologna reform efforts, the question arises whether and to what degree the declared goals of the Bologna Process (e. g. increasing student mobility and employability) have been achieved in the educational practice, i. e. on the individual university level. This desire points to the question of what these goals exactly are, how they are structured and how to eventually prioritize among them. The search for a comparable systematisation of the reforms objectives unveils only its absence.

This paper presents the work of higher engineering education scientists on the development of a comprehensive understanding of the Bologna Process objectives, their interconnections and practical measures in order to make this large scale reform accessible to the controlling of European universities' decision making. To this aim, the objectives are mapped in the form of a software based system model, according to the theory of *System Dynamics*. The elements of the model are fully based on the official Bologna declarations, memoranda as well as expert literature. It therefore claims to represent the state of the art on the goals of the Bologna Process. For the first time this system model structures the Bologna goals ordered by levels of hierarchy and it quantifies their dependencies on the basis of the *System Dynamics* approach. The validity of the model has been assessed based on qualitative and quantitative data, generated in a study involving 29 German experts in the field of higher education specialized on the Bologna Process. Further research will concentrate on a practical application of this system model, including the evaluation of the model's statements. Ultimately, the model's insights will enable European universities to estimate their respective degrees of Bologna goal attainment and to identify key measures for individual improvement.

**Keywords** Bologna Process Goals · System Model · Higher Education Reform

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# 1 Introduction

In the course of the Bologna Process, the European higher education area underwent comprehensive reform whose process of implementation and outcomes have reached both great public and scientific attention. Popular and scientific investigations mainly focus on the appropriateness and the effectiveness of the stipulated Bologna goals and their implementation in the pre-existing higher education systems of the individual member states. As a contrast, the present paper deals with the question of how the Bologna goals are actually interlinked and structured and how their achievement can be measured in several/individual universities. The research was deemed necessary, because of the great effort, universities and national higher education systems have put into the implementation of the reform, without being able to accurately measure their success.

For this purpose an instrument has been developed, based on a complex system model, which effectively maps the various objectives of the Bologna Process including its resulting measures on the institution level. For the first time, this model illustrates and hierarchically structures the entirety of the Bologna goals. By putting the latter into context and by weighing them, universities are able to identify strengths and opportunities in their individual implementation of the Bologna Process. Alongside, the model also systematizes the content of the Bologna declarations by distinguishing genuine objectives from mere measures, which are not desired goals in their own right, but rather agreed upon solutions in order to achieve the chosen objectives. On this basis, European universities can now estimate their individual degree of Bologna goal attainment and hence evaluate both their needs for further optimization and justified content.

The work is part of the effort undertaken by the Competence and Service Center for Teaching and Learning in Engineering Sciences – TeachING-LearnING.EU [1] – to sustainably improve the quality of engineering science courses in the context of the Bologna Process. The Competence and Service Center, based at the RWTH Aachen University, the Ruhr-Universität Bochum and the Technische Universität Dortmund, will use the model as a benchmarking tool, in order to identify best practices and expand the insights into effective institutional policies for the engineering sciences education. The piloting application of the Center's insights will be conducted at very large engineering universities in Germany, like the RWTH Aachen University [2].

This paper presents and discusses the methodological development of the resulting Bologna goal system model, as well as some key findings. In the following an overview of the theoretical background of the Bologna Process is provided as well as of the approach of the presented research.

## *1.1 Theoretical Background*

Based on their agreement in Sorbonne, in 1999 29 European countries declared to reorganize their higher education systems as specified by the Bologna declaration [3].

Within this arrangement, ministers of the participating European countries agreed on the concerted pursuit of the goal to use the "European area of higher education as a key way to promote citizens' mobility and employability and the Continent's overall development" [4], as it was laid out by the Sorbonne declaration of 1998 [5]. This general intention resulted on the policy level in the declaration of the following main objectives:

- increasing the compatibility and comparability of European higher education degrees,
- implementation of a two main cycles system (undergraduate and graduate),
- implementation of a system of credits – as in the ECTS,
- the promotion of mobility of students and scientific staff,
- promotion of European co-operation in quality assurance and
- promotion of the necessary European dimensions in higher education. [3]

In the course of the first decade of the new century both the number of countries participating in the Bologna Process as well as the number of objectives pursued increased. At least 46 ministers responsible for higher education in the participating European countries convened in Prague (2001) [4], Berlin (2003) [5], Bergen (2005) [6], London (2007) [7], Leuven (2009) [8], Budapest and Vienna (2010) [9] and Bucharest (2012) [10] to reaffirm their commitment to the determined goals and defined additional objectives for 2020, now under the title of the European Higher Education Area (EHEA) [11, 12]. The *promotion of the social dimension* [6] and *lifelong learning* [4] as well as the *increase of student participation* [4] and *international openness* [8] are examples for further goals added.

In order to structure the various goals, proclaimed in the Bologna declarations, researchers also try to identify and name superordinate goals. Ceylan et al. (2011) nominates three goals, central to the reform: "promotion of international mobility", "international competitiveness of universities" and "employability of graduates" [13]. As a comparison Witte et al. (2011) frames the top goals to be the "establishment of an attractive, competitive and fair European higher education area with a high mobility of students and scientific staff" [14]. To this day, there is yet no common understanding of one or several superordinate goals for the Bologna Process, not to speak of a comprehensive systematisation. For this reason the present research undertakes the effort to determine and structure these objectives, including the validation of what can be considered the one or several superordinate goals. As no standard method has been able to satisfy the requirements of this research situation, the process of identifying and nominating the super- and subordinate goals for the Bologna goals system model is now described in detail.

### *1.2 Description of Desk Research and Its Results*

The basis for the system model was a comprehensive study of primary and secondary literature on the Bologna reform. Since no comparable goal centric overview of the

Bologna reform had been produced prior to this research, the focus lied especially on the study of the official Bologna reform documents and their discussion in expert literature. In the following the pursued approach and the development of the model is outlined.

The present research *effort* began with the compilation of all Bologna documents, such as official declarations, memoranda and conference reports. In a first analysis all Bologna objectives have been extracted from the official declarations determined in Bologna [3], Prague [15], Berlin [5], Bergen [6], London [7], Leuven [8] and Bucharest [10]. The dependencies between individual goals have been identified based on their definitions.

Within the Bologna declarations, no differentiation has been made between superordinate goals and resulting measures which are to be directly implemented by universities. For example the Bologna goal *Establishment of a system of credits - the ECTS* [3] approved in the Bologna declaration of 1999 is not merely autotelic, but rather represents a measure to achieve superordinate goals such as *Promotion of Mobility* [3]. Within the model, all Bologna goals have been structured on the basis of their interdependencies and hence their underlying level of abstraction. A major result of the applied desk research thus is the identification of a set of highest-level objectives.

Three central dimensions of the Bologna Process have been recognized (see also Fig. 1): economic efficacy [4], scientific efficacy [4] and social cohesion (the so called "social dimension") [4]. Economic efficacy is mainly influenced by employability of graduates [3] and research findings with commercial relevance [5]. Employability is directly and indirectly rooted in the factors subject-specific competences [16], generic competences (transferable skills) [5], efficiency of academic teaching [16], work experience of graduates [16] and adaptability of graduates [16]. Scientific efficacy is determined by scientific competitiveness of the European higher education area [4], which in the context of the Bologna Process is itself based on the efficiency of university research [4]. Figure 1 is an extract of the software-based mapping of the Bologna goals. It shows the first three levels of the complex system model.

In the context of the Bologna Process, *participative equity* [7], *lifelong learning* [3], *intercultural understanding* [6] and *responsibility of individuals* [16] form the basic components of the dimension *social cohesion* [4]. As direct and indirect impacts on these variables can be identified e. g. *intercultural competences of graduates* [6], *equal access to academic programmes* [5] and *ability to participate in higher education* [7]. Between the three central dimensions, strong connections are found in the form of abstract factors and practical measures. Central factors, which relate to more than one dimension, are e. g. the *efficiency of academic teaching* [16], *mobility of students and scientific staff* [3] and *adaptability of graduates* [16].

As previously mentioned, no official global objective has been proclaimed for the Bologna Process. Yet, in order to incorporate all objectives in a single model, such a superordinate, unifying objective is needed. The task therefore was to find a term which summarizes the three highest-level goals *economic efficacy efficacy* [4] and *social cohesion* [4]. Unarguably the mentioned goals are all part of common national or international political agendas, which leads to the question [4], *scientific*

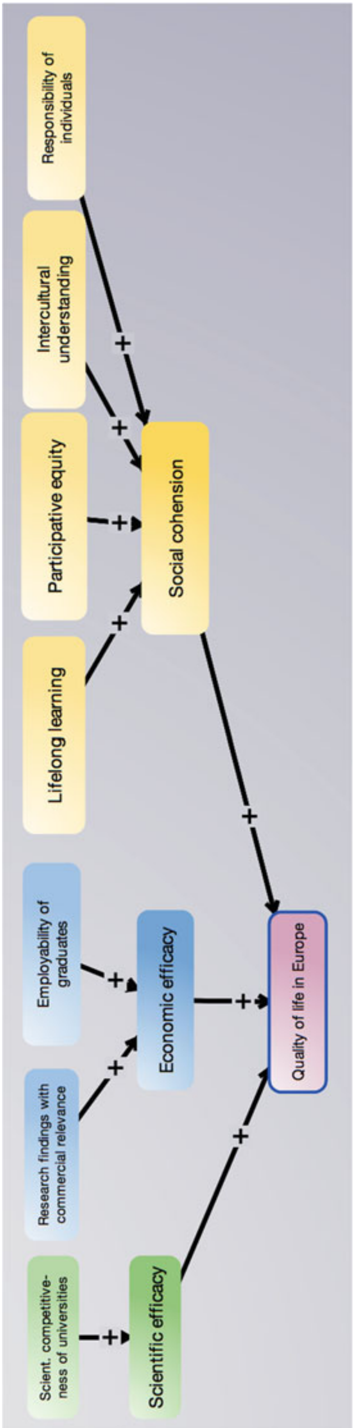


**Fig. 1** Illustration of the primary levels of the Bologna system model

of the superordinate purpose of such societal action. Studying the field of societal goals development one finds the terms *happiness* or *quality of life*, which are defined and used in such a way to frame the global aim of human actions [17, 18]. In consequence, the item *quality of life* in Europe was incorporated as the unifying top-level goal within the model.

In the next chapter the theoretical background of the mapping of the Bologna Goals is laid out. Furthermore the software-based illustration of the complex Bologna system model is outlined.

## *1.3 Description of the System Model*

### 1.3.1 Theory of System Dynamics

The theory of System Dynamics (SD), developed by Jay W. Forrester and advanced by John D. Sterman [19] serves as the basis for the present Bologna system model. "System dynamics is a perspective and set of conceptual tools that enable us to understand the structure and dynamics of complex systems" [19]. According to the method, all relevant factors influencing the considered problem scenario and its context as well as their interrelations have to be represented in the system model. The goal is to identify and illustrate the importance of the various factors involved as well as the direct interactions and multi-level cause-and-effect relationships between them. To do so, the technique allows to structurally and quantitatively reproduces the magnitude of effects, the emergence of indirect effects (through feedback loops) as well as the potential delays of certain effects (e. g. through long-term influences). The benefit of the method lies in the functionality to enable the understanding and simulation of complex and dynamic problem scenarios [19].

In order to achieve the depicted goal, SD combines qualitative and quantitative modelling techniques. In qualitative modelling, the relevant factors, their dependencies – i. e. positive or negative influences – and the magnitude of the effects – i. e. an abstract quantification expressed in percent of the total influence – can be illustrated. As a result, the key variables contributing to the realisation of the various objectives can be identified, performing a factor analysis. In addition to that in quantitative modelling concrete values can be plugged in the factors of the system model (such as *number of students in European universities*) and an explicit result of goal attainment can be calculated.

### 1.3.2 Software-Based Illustration of the Bologna System Model

The complex Bologna system model was developed using the modelling software *Consideo iMODELER* [20] which supports a mapping of factors and their interdependencies. Associations are represented as positive or negative influences and characterised as small, medium or strong connections. Besides this qualitative description of dependencies the software also allows the quantification of the extent –

e. g. measured in percentage points – by which one factor is influenced by another. Significant variables in the model could be identified by so-called “matrices of effects”. In context of the Bologna Process this analysis allows to recognize important measures, which are relevant for the achievement of individual Bologna goals.

In the Bologna system model, qualitative and quantitative modelling have been realized. On the basis of the three dimensions *economic efficacy, scientific efficacy* and *social cohesion* all relevant factors of the Bologna Process were assigned to their superordinate variables according to their direct influence. In this way all Bologna goals and measures were hierarchically structured. Therefore the first levels illustrate the major objectives of the Bologna Process, which have the highest level of abstraction. As an excerpt from the total concept, the latter are shown in Fig. 1. The full model can be accessed through the TeachING-LearnING.EU website’s chapter “Innovative Hochschuldidaktik” and “Best Practice Europa” [18].

The end nodes of the system model finally represent tangible measures, which represent common implementable means for individual European universities in order to improve the status of the mapped Bologna goals. One simple example for such an end node is the *implementation of the European Credit Transfer System (ECTS)*. The ECTS represents a solution in order to achieve the Bologna goal of *Compatibility of European qualifications and degrees*. By quantitatively evaluating the degree of realization of these measures and by knowing the relation between measures and objectives, one can ultimately calculate the degree of achievement of the dependent Bologna objectives. In order to allow such a calculation though, the quantification of the relations between any two model items was necessary. As an example:

- If a university has implemented the ECTS in the case of 80 % of its offered degrees,
- and if the implementation of the ECTS is evaluated to be responsible for 50 % of achieving the Compatibility of European qualifications and degrees,
- then this subordinate Bologna goal is met by this university by 40
  The quantification of the relations of the system model constitutes both an important and novel step for this research. It was therefore done through the effort of an expert consultation with a large panel size (see 2.1).

## 2 Validation of the Model and Its Results

### *2.1 Participants*

To ensure objectivity and thereby to verify the content validity of the system model, an expert consultation was performed. Inaccurate illustrations of the Bologna goals and incorrect interpretations of their qualitative dependencies were ascertained and rectified in this manner. Since the study also aimed at quantifying the interrelations between the various Bologna goals, the participants were asked to estimate the strength of each dependency. For this reason qualitative and quantitative data were gathered in the study.

The participants were composed of 29 German experts in the field of higher education research. An additional criterion in the selection process was an intensive occupation with the Bologna Process in research or work on the side of the experts. Participants were recruited by telephone and email contacts. In this communication process the previous experiences with the topic were investigated. The participation in the study occurred on a purely voluntary basis. Also, the chosen form of online questionnaire was designed to not collect any personal data about the participants. Thus a detailed description of the sample is not possible. For further details on the panel, see Sect. 3.2. . . .

## *2.2 Materials and Procedure*

To conduct the survey, an online-questionnaire has been designed using the software Unipark [21]. There, each question covers the influence of one model element on the other. Due to the considerable number of resulting questions and thus amount of time needed to complete the questionnaire, the survey has been divided into three parts. The participants have then been asked to respond to only one of these modules, while ensuring at the same time, that each module has been evaluated by at least ten experts. Each module dealt with one of the major dimensions of the Bologna Process system model. In total the questionnaire contained 47 items. It took around 30 min to complete one part of the questionnaire. After completing their chosen module, participants have been asked to continue the questionnaire on a voluntary basis in order to answer the other modules.

The questionnaire aimed at the verification of the collected variables and a quantification of the dependencies among the items of the presented system model. Consequently all variables and dependencies of the model have been investigated in the survey. At first, participants have been asked to estimate dependencies between the variables of the system model. As previously described, the structural mapping of the variables creates a hierarchy among them. As a result a distinction has been made between indicators on the one hand and higher target variables on the other hand. For example the factor *employability* is an indicator for the target variable *economic efficacy*. According to that, participants evaluated if and to what degree an indicator (e. g. *employability*) influences a target variable (e. g. *economic efficacy*). All ratings of dependencies between indicators and target variables have been made on a numeric five-point scale ranging from 0 to 100 %. Furthermore participants have evaluated the so called "explained variance" of the target variable, measured in percentage points. The value expresses the experts' opinions, about the degree to which the behaviour of a given target variable (e. g. *quality of life in Europe*) is explained by the set of the variable's influencing factors (e. g. the set of *economic efficacy*, *scientific efficacy* and *social cohesion*).

Qualitative data has been gathered from statements and additional explanations in specific text boxes for commentary. There, participants have been primarily asked to assess the accuracy and the completeness of variables, indicators and their dependencies. In order to support the experts' understanding of the questionnaire, a software-based online illustration of the system model has been given with assistance of an online-application of the Considedeo iMODELER [20].

## *2.3 Analysis of the Data*

This chapter deals at first with the analysis methods of the qualitative and quantitative data gathered by the expert consultation. After that, the central results of the investigation are presented. Table 1 summarizes the most important results of the quantitative analysis of the expert consultation.

### 2.3.1 Analysis of Quantitative Data

The Quantitative data comprises all ratings of dependencies between the variables of the Bologna system model and the estimation of the explained variance of these factors expressed by the participants of the expert consultation. A descriptive statistic of the quantitative data has been calculated using the software *SPSS* [22]. Data of one participant has been excluded from the data analysis because of invalid values. The sample sizes for individual items ranges from $n = 9$ to $n = 28$ depending on their distribution in the questionnaire.

On the basis of the average estimation of dependencies, a so-called *absolute dependency* between every variable has been calculated for the quantification of the system model. This parameter relativises the average numeric dependency between two variables taking into account the explained variance.

Based on the expert ratings and the resulting *absolute dependencies* an estimation of the importance of individual indicators for a target variable is possible. According to the percentage of *absolute dependency*, e. g. the indicator willingness to *lifelong learning* [10] shows a greater impact on the target variable *lifelong learning* [3] than *efficiency of academic teaching* [10] or *flexibility of academic programmes* [5]. In conclusion a consideration of the parameter *absolute dependency* enables an identification of the most important measures in the context of the Bologna Process.

## *2.4 Analysis of Qualitative Data*

The qualitative data from the expert consultation consists of statements, which have been contributed in the extra text fields in the online-questionnaire. All comments have been analysed against the benchmark of their significance within the Bologna declarations, memoranda and expert literature.

**Table 1** *Extract of the results of quantitative data analysis of the expert consultation*; The element *n* represents the sample size, *r* the range, *M* the mean and *SD* characterises the standard deviation of the expert ranking

| No. | Variable | Indicator | n | r | M | SD | Explained variance (in %) | Absolute dependency (in %) |
|---|---|---|---|---|---|---|---|---|
| 1 | Quality of life in Europe | Economic efficacy | 28 | 50 | 74 | 16 | 61 | 21 |
| | | Scientific efficacy | | 75 | 64 | 21 | | 19 |
| | | Social cohesion | | 75 | 74 | 16 | | 21 |
| 2 | Economic efficacy | Employability | 17 | 50 | 76 | 16 | 70 | 70 |
| 3 | Mobility | Financial support (mobility) | 16 | 50 | 80 | 21 | 76 | 25 |
| | | Institutional support (mobility) | | 50 | 84 | 15 | | 26 |
| | | Compatibility of European qualifications and degrees | | 50 | 78 | 18 | | 24 |
| 4 | Compatibility of European qualifications and degrees | Modularization of studies | 16 | 75 | 64 | 22 | 69 | 22 |
| | | Implementation of ECTS | | 75 | 75 | 22 | | 26 |
| | | Study contents based on international standards | | 75 | 62 | 22 | | 22 |
| 5 | Social cohesion | Intercultural understanding | 14 | 50 | 68 | 18 | 64 | 17 |
| | | Lifelong learning | | 75 | 59 | 25 | | 14 |
| | | Participative equity | | 50 | 77 | 18 | | 19 |
| | | Responsibility of individuals | | 99 | 66 | 27 | | 16 |
| 6 | Lifelong learning | Efficiency of academic teaching | 14 | 99 | 59 | 25 | 76 | 10 |
| | | Willingness to lifelong learning | | 50 | 89 | 16 | | 15 |
| | | Range of academic programmes | | 75 | 75 | 24 | | 13 |
| | | Equal access to academic programmes | | 50 | 75 | 20 | | 13 |

**Table 1** (Continued)

| No. | Variable | Indicator | n | r | M | SD | Explained variance (in %) | Absolute dependency (in %) |
|---|---|---|---|---|---|---|---|---|
| | | Flexibility of academic programmes | | 50 | 80 | 14 | | 13 |
| | | Counselling to educational programmes | | 50 | 80 | 14 | | 13 |
| 7 | Ability to participate in higher education | Flexibility of academic programmes | 14 | 75 | 73 | 23 | 74 | 19 |
| | | Learning support | | 75 | 70 | 22 | | 18 |
| | | Efficiency of academic teaching | | 75 | 68 | 23 | | 18 |
| | | Financial support (social gaps) | | 75 | 75 | 26 | | 20 |

The purpose of the present system model is to provide an objective mapping of all Bologna goals based on the official Bologna literature. Therefore a central problem of the qualitative analysis was to distinguish comments and supplements based on Bologna literature from additional evaluations, often rooted in subjective criticism of the Bologna Process. A few experts suggested further variables such as "health" or "cultural identity", which are not part of the goals of the Bologna Process, or missed the inclusion of criticism of the present higher education system in the system model. Such statements have been dismissed for addition to the system model.

In the expert comments the superordinate Bologna goal of *quality of life in Europe*, chosen to unify the various Bologna goals, has been questioned in several cases. Yet, no argument has been brought forward, which would have disrupted the logic of the argumentation, laid out in Sect. 1.2.

In the course of the analysis of the qualitative data, the majority of the variables and dependencies of the system model have been re-evaluated and verified. This allowed for example to confirm the dependency of the factor *adaptability of graduates* [16] from the Bologna factors *mobility* [3], *intercultural programmes* [6], *external internships within studies* and *reflective faculty*. In addition, the definitions of the variables have been extended based on the statements. Moreover indicators have been added to respective target variables (e. g. new indicators for the factor *quality of academic staff* are *attractiveness of the university* [5], *quality of personnel selection* and *personnel development*) and additional connections between factors have been established. As a result, the verification of the model based on the qualitative data of the expert consultation delivered the pursued effect.

# 3 Discussion of the Results

## *3.1 Summary*

The purpose of the present research was the development of a measuring instrument, which would enable universities to estimate their individual degree of Bologna target achievement, based on a complex system model of the Bologna goals. The system model was generated based on desk research of the official Bologna documents, including Bologna declarations, memoranda and expert literature. An expert consultation based on an online-questionnaire was performed in order to verify the system model and to quantify the dependencies between its variables.

As a result of the expert consultation, modifications of the initial Bologna system model have been applied. Illegitimate interdependencies were removed and new connections as well as new variables were added. In addition, the definitions of the variables were further detailed for reasons of clarification and precision. Consequently the intended verification of the system model has been achieved. On top of that, a quantification of the dependencies among the model's elements has been realized. The quantification of the *absolute dependencies allowed* the calculation of the individual importance of the various measures, available to a university.

## *3.2 Limitations of the System Model*

As previously described the presented system model is based on an intensive desk research. A first verification of the system model has been achieved by performing an expert consultation. Within this study a highly satisfactory number of $N = 28$ complete data records has been considered in analysis. Moreover the knowledge of the involved experts in Bologna as well as their willingness for participation in this study have been proven through a combined telephone and email-communication. Nevertheless, *difficulties* of misinterpretation result from this validation method:

The experts participating in the survey have done so on a voluntary basis; nonetheless there is no certainty that all statements have been given conscientiously. There has been no control of conditions during the responding to the online-questionnaire. Moreover problems in understanding the method of the system model or the online-questionnaire have only been identified on the basis of the comments in the commentary text boxes. In addition to that, it is possible that relevant variables of the Bologna Process have been overlooked during the desk research or by the experts.

A major point of discussion in the expert consultation has been the global objective of the system model, i. e. *Quality of life in Europe*. Despite the subjective nature of these comments and their shortcoming to disrupt the argumentation put forward to make use of this specific item, it will continue to have to withstand further scrutiny.

As another result of the expert consultation the model has been modified. New variables as well as dependencies have been implemented and unnecessary connections and factors of the model have been removed. Statements of the experts initiated these modifications. Given the fact that the system model is an attempt to illustrate all Bologna goals objectively, a few expert statements have been excluded from analysis according to their inadequacy (e. g. subjective criticisms of the Bologna Process or comments relating to the desire for ideal conditions of higher education). Since the criterion for the exclusion of additional factors and expert comments is their observed relevance within the available Bologna literature, the definition of exact system boundaries cannot be achieved terminally. Due to the interpretive character of an object of study like a political reform, it is not possible to reduce the blurredness of the system boundaries to an immaculate degree.

Overall, the conception and evaluation of the presented system model has raised various questions regarding the content, depiction and conclusions of the Bologna reform, as well as the feasibility of achieving the aim of mapping its goals in the first place. The investigation of these questions therefore has to be the subject of further research.

### *3.3 Further Research*

The purpose of this research was the development of a measuring instrument, which enables universities to estimate their individual Bologna goal achievement. The basis for this measuring instrument is the presented system model. For this reason further research will concentrate on the operationalisation of the end nodes of the model, i. e. measures available to the universities in order to achieve the Bologna Goals. On the basis of the operationalised system model a questionnaire will be designed. By means of the questionnaire the degree of achievement of the implementation of the Bologna Process in universities will be estimated within a pilot study at three German universities. By applying the collected data to the system model, the total degree of attainment of the Bologna goals will be calculated concerning these individual institutions.

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# International Student Mobility in Engineering Education

**Ute Heckel, Ursula Bach, Anja Richert, Sabina Jeschke and Marcus Petermann**

**Abstract** Engineering students are, compared to their counterparts in other disciplines, less mobile resulting in limited intercultural skills. Globalization requires professionals being excellent in their fields and being able to work on a global scale at the same time. So far, engineering education has put too little stress on integrating intercultural competences into curricula. This paper shows new approaches to incorporate international experiences into higher engineering education. First, it analyzes the current situation of international student mobility in Germany, before emphasizing the general motivation for international student exchange especially in engineering science. A consortium of three excellent German engineering universities was put up to introduce new measures for increasing student mobility as is described subsequently. This paper represents work in progress. Thus, further results will be published continuously.

**Keywords** International Student Mobility · Inbound · Outbound · Engineering Education · Curricula Development · Intercultural Competences

## 1 Introduction

In Germany international student mobility in engineering science lies below average compared to other disciplines. Even the Bologna reform of introducing joint degrees throughout Europe did not result in higher numbers of engineering students going abroad (referred to as "outbound mobility") [1]. Also, the number of foreign engineering students coming to Germany (referred to as "inbound mobility") especially from industrialized countries such as the US, the UK, Japan, or France is below expectations [2].

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In order to educate excellent engineers, intercultural competences are essential. Engineering is not limited by national borders. Not only big multinationals but also small and medium sized enterprises, where most engineers are employed in Germany, compete on global markets generating the need for intercultural competent employees. Thus, excellent universities, that aim to educate excellent engineers, have to face the challenge of integrating international experiences into engineering curricula.

A consortium of three excellent German universities, RWTH Aachen University (RWTH), Ruhr University Bochum (RUB), and Technical University Dortmund (TUD), was put up to develop new approaches for improving higher engineering education. First, the partners worked together to build the "Competence and Service Center for Teaching and Learning in Engineering Science – TeachING-LearnING.EU" [3]. Within the project ELLI ("Exzellentes Lehren und Lernen in den Ingenieurwissenschaften" Excellent Teaching and Learning in Engineering Science) the same partners discuss key issues of engineering education also focusing on international student mobility.

After introducing basic terms and definitions (Sect. 2), the paper gives an overview over international student mobility numbers in Germany (Sect. 3) and introduces the basic motivation of students, higher education institutions (HEI) and industry to promote international student exchange in engineering education (Sect. 4). Key measures proposed within the project ELLI to foster student exchange in the field of engineering education are presented (Sect. 5) together with their expected impact (Sect. 6). The paper represents work in progress that will be put into practice during the next 5 years. Concrete results will be published continuously.

## 2 Terms and Definitions

When talking about mobility and mobile students some basic terms have to be defined. According to the definitions of [2, 4, 5] the following terms are introduced:

- National student: student with German nationality.
- Foreign student: student with a nationality different from Germany.
- Bildungsinlaender students: foreign students who gained their higher education entrance qualification at a German school or who passed a Gifted Students Test (Begabtenprüfung) or an Aptitude Test (Eignungsprüfung) in Germany.
- Bildungsauslaender students: foreign students who gained their higher education entrance qualification at a foreign school and/or complemented their foreign school qualifications by attending a German Studienkolleg (preparatory course for higher education admission).
- Mobile students: students who cross national borders for the purpose or in the context of their studies.
- Inbound mobile students: students who move to a country for the purpose of study or study related activity.

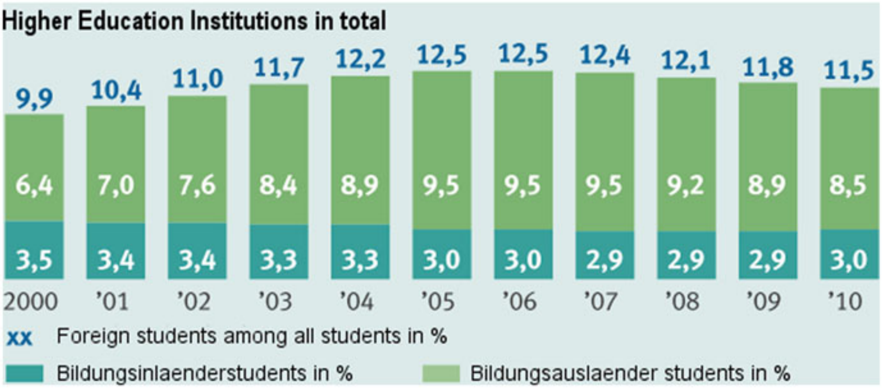


**Fig. 1** Foreign students as a percentage of all students in German HEI [2]

- Outbound mobile students: students who leave their country to another for the purpose of study or a traineeship in the context of study.
- Inbound mobility: refers to the number of inbound mobile students.
- Outbound mobility: refers to the number of outbound mobile students.
- Country of origin: the country where the student moves from.
- Country of destination: the country which the student moves to.

Using those definitions, the next section introduces statistics showing the current mobility activities of students in Germany.

## 3 Statistical Background

The Bologna reform focused on structural changes to increase student mobility throughout Europe as a central goal. In 2009 the European Ministers of Education and Research set the aim that until 2020 20 % of European students should have lived and worked abroad. On the conference in Budapest and Vienna in 2010 it became clear that this goal will not be accomplished [6]. This section gives an overview over current inbound and outbound mobility data in Germany in general and on university level mainly based on the survey carried out by the Hochschul-Informations-System (HIS) in co-operation with the German Academic Exchange Service (DAAD) [2].

### *3.1 Inbound Mobility at German HEI*

In 2010 11.5 % of students in Germany were foreign students (c.f. Fig. 1). In 2009 the most common countries of origin were China (10 %), Turkey (9.9 %) and Russia (5.2 %). 16.5 % of foreign students were enrolled in engineering studies with

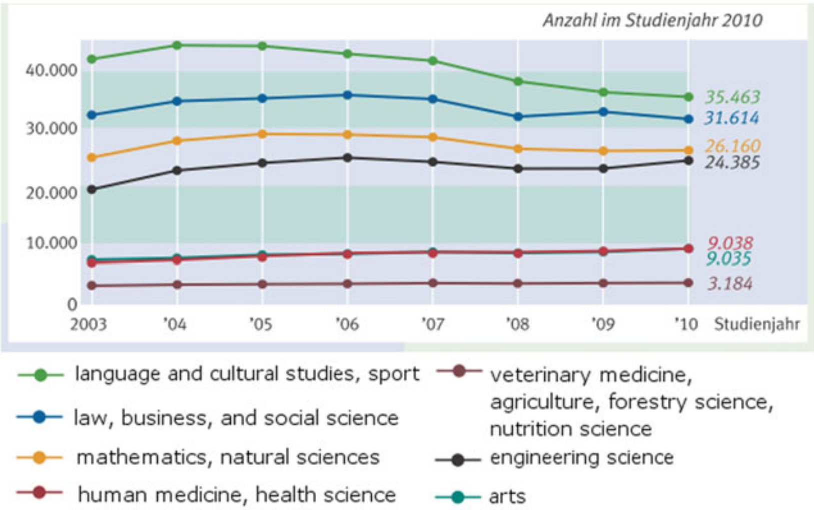


**Fig. 2** Bildungsauslaender students at universities, by subject group [2]

mechanical engineering (5.9 %) and electrical engineering (4.5 %) being the most popular engineering disciplines.

In terms of subject preferences most Bildungsauslaender students are inclined to choose courses in language and cultural studies and show less interest in engineering as is shown in Fig. 2.

### *3.2 Outbound Mobility at German HEI*

In 2008 4.2 % of national German students pursued their studies abroad. Depending on the degree different countries of destination were most popular: 40 % of German bachelor students pursuing their studies abroad choose The Netherlands as their country of destination, 37 % of German doctoral students abroad were enrolled in Switzerland and 61 % of students with other degrees (such as diploma or master) took up studies in Austria. As is shown in Fig. 3 the neighboring countries seem to be most attractive to German students with Austria and the Netherlands being the most visited countries as well as the UK and the US as Anglophone countries.

Compared to other countries German students are rather mobile. In France only 2.9 % of national students went abroad, in the UK only 1.2 % and in the US 0.3 %. In other countries such as Ireland (10.4 %), Slovakia (11.8 %), or Iceland (21.8 %) national students choose their course of studies more often abroad than in Germany. The reason for this lies in the higher education system of those countries not being able to provide enough capacities to enroll all of their national students. Thus, those students are more often and to a higher degree mobile than students in other nations

| Destinations | Quantity | Amount |
|---|---|---|
| Austria | 20.019 | 19,6 |
| The Netherlands | 18.972 | 18,6 |
| Great Britain | 12.895 | 12,6 |
| Switzerland | 11.005 | 10,8 |
| USA | 9.679 | 9,5 |
| France | 6.071 | 5,9 |
| Australia | 3.418 | 3,3 |
| Sweden | 3.400 | 3,3 |

**Fig. 3** German students abroad in 2008, by country of destination in percent [2]

[5]. China, India, and South Korea are currently the countries with the highest outbound mobility rates [7].

Mostly national students from language and cultural studies envisage a mobility period in their course of studies (12 %). The lowest rate of outbound mobility is encountered among engineering students (4 %). Thus, in terms of subject preferences inbound and outbound mobile students show similar priorities (c.f. Fig. 2).

Regarding the development within the last 17 years, mobility rates developed differently throughout the disciplines as is shown in Table 1. Since 1994 mobility rates in language and cultural studies stayed constantly at a high level (1994: 12 %, 2000: 13 %, 2009: 12 %) whereas students in e. g. engineering science became a lot more mobile over the same timespan where mobility rates nearly doubled between 1994 (2 %) and 2009 (4 %) [7].

Regarding the disciplines different ways of foreign exchange seem to be commonly chosen by students. Students of language and cultural studies often chose to pursue their studies abroad whereas engineering students prefer to take up internships in the respective country of destination as is shown in Table 2 [7].

**Table 1** Rate of mobile students, by discipline in percent [7]

| Disciplines | Year | | | | | |
|---|---|---|---|---|---|---|
| | 1994 | 1997 | 2000 | 2003 | 2006 | 2009 |
| Engineerings | 2 | 3 | 4 | 4 | 3 | 4 |
| Language and cultural studies | 12 | 12 | 13 | 12 | 12 | 12 |
| Maths/nat. s. | 4 | 5 | 4 | 5 | 5 | 5 |
| Medicine/health | 4 | 5 | 5 | 7 | 6 | 5 |
| Law and business studies | 5 | 8 | 9 | 8 | 9 | 11 |
| Social/education s. psychology studies | 2 | 4 | 4 | 5 | 6 | 8 |

**Table 2** Rate of mobile students with study-related activities, by discipline in percent [7]

| Disciplines | Studies | | Internship | | Language course | | Other | |
|---|---|---|---|---|---|---|---|---|
| | 06 | 09 | 06 | 09 | 06 | 09 | 06 | 09 |
| Engineering s. | 3 | 4 | 6 | 7 | 2 | 1 | 1 | 1 |
| Language and cultural studies | 12 | 12 | 9 | 8 | 7 | 6 | 4 | 4 |
| Maths/nat. s. | 5 | 5 | 5 | 5 | 2 | 1 | 2 | 2 |
| Medicine/health | 6 | 5 | 18 | 16 | 3 | 2 | 3 | 2 |
| Law and business studies | 9 | 11 | 9 | 7 | 5 | 3 | 1 | 1 |
| Social/education s. psychology | 6 | 8 | 7 | 7 | 3 | 3 | 2 | 2 |

### *3.3 International Mobility Rates on Institutional Level*

The picture is also mirrored in statistics on institutional level. The following numbers represent international student mobility at RWTH being also emblematic for RUB and TUD. In the winter term of 09/10 32,943 students were enrolled in study programs at RWTH Aachen University with the faculties of mechanical engineering (8721 students), civil engineering (1340 students) and electrical engineering and information technology (3106 students) being one of the biggest faculties of RWTH. In 2009 624 German students took part in international exchange programs to pursue a part of their studies abroad. The most popular countries were Spain, France and the UK [8].

More than 5000 foreign students contribute to an international profile of RWTH. In the winter term (wt) 09/10 5164 foreign students were enrolled in courses at RWTH which amounts to 15.7 % of all students (c.f. Fig. 4).

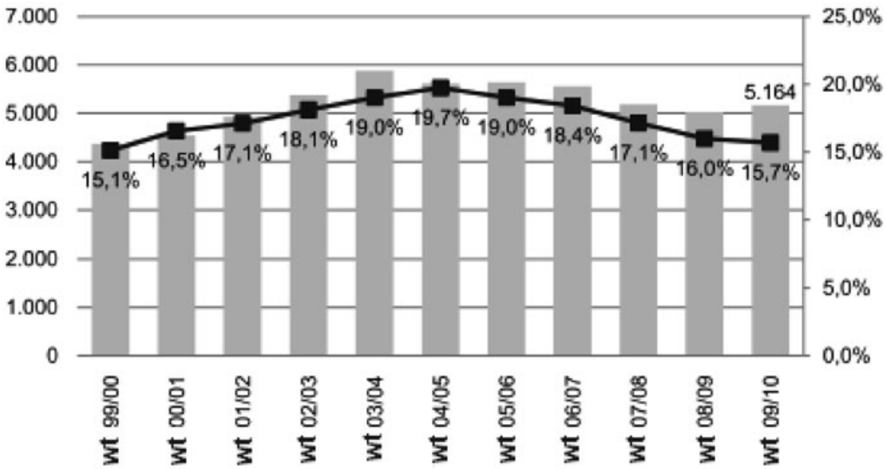


**Fig. 4** International students at RWTH in winter terms 99/00 – 09/10 [8]

**Table 3** Rate of mobile students with study-related activities, by discipline in percent [2]

| Study-related problems | Bachelor university | Master university |
|---|---|---|
| Loss of time | 35 | 30 |
| Little support from HEI | 24 | 21 |
| Financing problems | 22 | 23 |
| Limited compatibility with study specifications | 26 | 20 |
| Difficulties finding an apartment | 18 | 20 |
| Problems with recognition of records | 21 | 13 |

Despite of mobility programs initiated by the Bologna reform numbers remained constantly at the same level between 1999 and 2010. The biggest community of foreign students is stemming from China, followed by Turkey and Luxemburg [8]. Fewer than 100 students from countries such as the US, UK, France, and Japan pursued their studies at RWTH in 2009. The most popular faculties among foreign students are the faculties of mathematics, computer science and natural sciences (21 %), the faculty of mechanical engineering (20 %) and the faculty of electrical engineering and information technology (14.3 %). RWTH ranks sixth among the most popular universities for foreign students in Germany [8].

Those numbers show that there exists a discrepancy between inbound and outbound mobility with a lot more foreign students being enrolled in German universities than German students attending courses abroad. Furthermore, only a low percentage of foreign students from the industrialized world take part in German university programs. The following section gives an overview over basic reasons for these phenomena.

## 4 Motivation for Mobility

The reasons for small numbers in outbound mobility are multifaceted (c.f. Table 3). Compared to former German higher education degrees such as the diploma, new curricula developed throughout the Bologna reform (i. e. the bachelor degree) seem to be less flexible leaving the students not enough time to spend a semester or more time abroad. 35 % of bachelor students and 30 % of master students at universities state that they consider a temporary stay abroad as a loss of time [2]. Furthermore, insufficient mutual recognition of studies and qualifications present major problems. 21 % of bachelor students and 13 % of master students at universities report problems in the recognition process of their records accomplished abroad. Also financial problems, little support from higher education institutions (HEI), and mandatory industry internships during semester breaks seem to hamper the students' opportunities to integrate stays abroad into their courses of studies.

The factors motivating German students to take part in foreign exchange programs are manifold. The prospect of developing personal and professional skills seems to

**Table 4** Experiences of German students during study-related visits abroad, by type of degree in percent [2]

| Experiences | Bachelor university | Master university |
|---|---|---|
| Managed to deal with the foreign mentality | 81 | 84 |
| Gathered new experiences | 86 | 81 |
| Feeling of being integrated | 72 | 68 |
| Accomplished all planed records | 63 | 72 |
| Took part in all classes as intended | 63 | 69 |
| Successful communication in foreign language | 70 | 63 |
| Very good support | 63 | 68 |
| Transfer of important discipline-specific knowledge | 47 | 50 |
| Learned a lot about the future profession | 40 | 43 |

be the main motivator. But also other positive experiences were reported by German students abroad as is shown in Table 4 [2]:

German engineering education is highly regarded in emerging countries resulting in increased inbound mobility rates from China, or India whereas inbound mobility from Western countries stays rather low (c.f. Sect. 3). Engineering students from the industrialized world seem to be attracted to strong research nations and English speaking countries such as the US, the UK, Canada, or Australia. From a research perspective it is crucial to attract students from industrialized nations in order to intensify connections between German and other leading research universities in the industrialized world, to boost research excellence, and to broaden networks for research and education.

From an industry perspective intercultural skills play a major role in engineers' professional profiles. Due to globalization, companies do no longer operate on local but on global markets. Therefore, students have to be prepared to face the challenges of globalized businesses. Thus, international and intercultural skills will have to be integrated into engineering education [9].

Shortages of skilled workers and managerial staff in Germany increase the demand for highly skilled foreign workers. Especially the potential of female engineers is not yet reached. With currently 10 % female engineers, Germany lags behind other countries such as Portugal (24 %) or France (16 %) [10]. According to OECD statistics Germany also lies behind other western countries such as Sweden or Italy considering the number of female engineering graduates from higher education institutions as is shown in Fig. 5 [11].

Thus, attracting female students for higher engineering education in Germany might also bear the potential to solve the problem of current labor shortages.

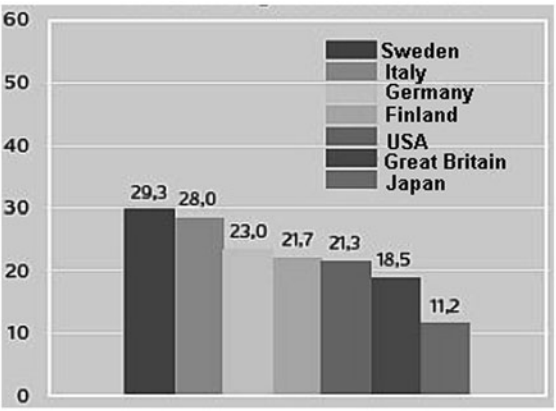


**Fig. 5** Female graduates in engineering science in 2004 in percent [11]

## 5 Measures for Increasing Student Mobility

Within the project ELLI (c.f. Sect. 1) RWTH, RUB, and TUD develop new measures to increase both inbound and outbound mobility rates. The following section describes those measures in detail.

### *5.1 Measures for Increasing Outbound Mobility*

The project ELLI aims to create a favorable framework enabling national students of each of the three universities to integrate at least one stay abroad during their course of studies. Therefore, the following measures will be put into practice:

- Measure 1: Establishment of a program for advancing international mobility,
- Measure 2: Development of an interactive mobility map,
- Measure 3: Integration of mobility periods in curricula.

#### 5.1.1 Measure 1: Establishment of a Program for Advancing international mobility

In a first step specific barriers hampering international student mobility at RWTH, RUB, and TUD are analyzed. Therefore, a survey is carried out among engineering students attending courses in undergraduate and graduate studies. As a result the introduction of a common international course record book will be envisaged. It aims at easier and faster recognition of study records accomplished abroad and will be developed in close co-operation with the international partners of the consortium (c.f. measure 2: interactive mobility map). The international course record book will be based on agreements concerning common learning outcomes and their evaluation at all partnering universities. But also new concepts and measures for integrating international mobility periods into the course of studies based on present strategies at the universities are discussed together with the international offices of each of the partnering universities. Furthermore, the program for advancing international mobility includes the development of an indicator system based on the already existing indicator system developed within the project TeachING-LearnING.EU (c.f. Sect. 1). Thus, quality of international study periods as well as compatibility of records between universities can be measured. The basis of the indicator system will be the annual number of international exchanges indicating the acceptance of the measure among students and its impact on the overall international student mobility.

The program will be implemented at the participating universities for 2 years. Moreover, professors will be supported in encouraging the best and most committed students for international study terms. Students planning their stay abroad will be supported by a comprehensive discipline-specific counseling service.

#### 5.1.2 Measure 2: Development of an Interactive Mobility Map

Mostly international exchange is organized through programs offered by funding organizations such as DAAD or others. But, successful exchange always relies on personal and informal contacts between professors enabling students to be exchanged between partnering institutions. Often students are not aware of the contacts of their home institution to other higher education institutions abroad. In order to increase transparent information transfer and the opportunities for students to find a suitable institution abroad, the development of an interactive mobility map is envisaged.

The contacts and networks of the professors bear a tremendous potential for exchange. In order to bring out this potential, the networks are analyzed especially focusing on common strategies and contents in teaching and research. Following a bottom-up approach, an interactive mobility map of Europe and/or the world is developed that integrates personal contacts of professors as well as general contacts of each participating university. Already existing mobility maps such as moveonnet.eu [12] are adapted according to the purposes of the consortium. The interactive mobility map will be made available online supplemented by a mobile App. Additionally students will be able to upload discipline-specific experience reports as well as to integrate further metadata through geo-tagging. The map will be maintained by the ELLI consortium to guarantee discipline-specific contents in teaching and learning in engineering science. The interactive mobility map will be evaluated regularly using surveys among its users.

#### 5.1.3 Measure 3: Integration of Mobility Periods in Curricula

Mutual degree recognition and accreditation are central topics of the Bologna process and the development of the European Higher Education Area. The aim is to facilitate the recognition of study records accomplished at a foreign research institution. Therefore, common quality standards for the recognition process as well as harmonized curricula have to be developed [13].

Due to different contents taught in the institutions of higher engineering education across the borders, recognition of foreign study records is still difficult. The measure aims at simplified recognition procedures to promote study-related stays abroad combined with industry internships. Therefore, curricula have to be made transparent between the participating universities and their international partners. In this regard double degree programs have a strong potential to enhance mobility periods. Common strategies to integrate international mobility periods into curricula will be developed together with the departments and faculties of the three German universities and their international partners as well as partners from industry. The aim is to design an individual plan listing all necessary study records or industry internships for each student. The evaluation of the measure integrates a survey during the students' stay abroad as well as after returning home.

## 5.2 *Measures for Increasing Inbound Mobility*

As shown above (c.f. Sect. 3) the majority of foreign students taking up their studies in Germany come from China, Turkey and Russia whereas German students often tend to choose their closest neighbors such as The Netherlands, Austria, or Switzerland and the English speaking countries such as the UK, or the US. In order to build fruitful co-operations for research and teaching, a balanced network of partnering universities has to be drawn up.

The project ELLI aims to create the necessary framework to increase numbers of foreign students mainly stemming from the industrialized world such as the US, UK, Japan, or France in order to balance the inbound/outbound ratio and to build connections to strong research nations. The measures are built on experiences gathered from former projects and initiatives. First experiences from joint projects between Drexel University Philadelphia and RUB show that courses provided during semester breaks are widely accepted. From the spring/summer term 2011 on, 11 students from the US take part at lectures and laboratory courses at RUB. Due to high standards in laboratory equipment, the demand from US students for German laboratory courses is very high. The courses are offered by German and American lecturers as block seminars in English and German. Furthermore, the project Undergraduate Research Opportunities Program International (UROP) at RWTH invites students from renowned universities in the US and Canada to pursue a 10-weeks research stay in Aachen during the summer break.

Based on those experiences, specific barriers hampering foreign students to integrate a stay in Germany into their curricula are analyzed in close co-operation with the network of international partners (c.f. interactive mobility map). Taking those findings into account, the three partners RWTH, RUB and TUD will develop curricula enabling foreign students to integrate a stay abroad easily into their course of studies. Furthermore, experiences gathered within the project RISE (Research Internships in Science and Engineering) where short term research internships of undergraduate students from the US, the UK, and Canada at German higher education institutions are funded by DAAD [14] as well as experiences from the International Summer Program (ISP) at TUD [15] for student exchanges during summer breaks will be laid down in the concept.

For example the effect of study courses being taught in English as well as harmonized curricula during term breaks will be evaluated. Therefore, concepts are developed for selected co-operations between German and international universities and put into practice over a period of 4 years. The evaluation is based on attendance rates and surveys among course participants. Long-term effects such as retention rates and successful career development of participants are explored.

## 6 Expected Impact

All of the proposed measures aim to increase inbound and outbound student mobility rates in engineering education. Intercultural competences already play a major role in nowadays professional profiles of engineers but will do so even more in the future. Due to globalized markets and companies acting on a global scale, engineers will have to cope with intercultural settings. Intercultural competences can only be gathered through international exchange. Approaches focusing on language courses or intercultural seminars “at home” do not prove to show sufficient effects on the participants’s intercultural problem solving competences [2]. Therefore, “true” exchange programs and measures inciting international student mobility will have to be put into practice. Programs do not start from scratch and will be adapted to current exchange programs at RWTH, RUB, and TUD. But also programs and measures are developed taking the special needs and circumstances of engineering education into account. Thus, the prominent integration of intercultural competences into the curricula of engineers will be at the center of the introduced measures within the project ELLI.

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# Massive Open Online Courses in Engineering Education

**Ute Heckel, Ursula Bach, Anja Richert and Sabina Jeschke**

**Abstract** Though higher engineering education generally lacks students in Germany, some universities are faced with the challenge of dealing with extremely high enrollment numbers due to recent changes in education policy. In the winter term 2011/2012 approx. 1,900 students enrolled for mechanical engineering and industrial engineering and management at RWTH (Rheinisch-Westfälische Technische Hochschule) Aachen University putting the educational skills of teachers to the test. Obviously, new concepts become necessary to find adequate teaching models.

Modern information and communication technologies have already become a constant part of everyday life among the new generation of students. But their full potential for higher education has not yet been exploited. Concepts hitherto focused on integrating technologies such as Audience-Response-Systems or mobile applications into face-to-face lectures. Only recently a new approach emerged, bearing the potential of teaching increasingly high numbers of students entirely online and of revolutionizing the higher education landscape: Massive Open Online Courses (MOOCs). They seem to highly motivate their students to actively participate in online courses and to interact with teachers and fellow students using social and technical networks. As demonstrated by initiatives such as the Khan Academy, udacity, edX, or Coursera MOOCs attract enormous numbers of students (In 2011 160,000 students followed the Stanford lecture on Artificial Intelligence by Prof. Thrun and Prof. Norvig with 23,000 earning a certificate).

This paper aims to show how MOOCs might help to tackle the challenges of teaching large classes in higher engineering education. As they have attracted large amounts of students especially for engineering topics, they might be adequate for higher engineering education. A variety of MOOCs have emerged so far based on fundamentally different learning principles that cater to the needs of engineering education in different ways.

Thus, this paper categorizes MOOCs according to their underlying didactical approaches in a first step. In a second step it is evaluated to what extend the different kinds of MOOCs can be used to implement active and problem-based learning in a large class and for what purposes in engineering education they can be best applied.

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The results are useful for any university teacher in higher engineering education dealing with large classes.

**Keywords** Large Classes · Higher Engineering Education · Active Learning · Problem-based Learning · Massive Open Online Courses

## 1 Introduction

German higher education institutions face the challenge of exceptionally large numbers of students enrolling for undergraduate courses due to recent changes in German education policy[1]. In contrast higher engineering education lacks sufficient graduates mainly due to high drop-out rates caused by challenging curricula, insufficient knowledge of natural sciences and mathematics acquired at school, and too few practical relevance of the learning material [1]. This situation results in the challenging task for higher engineering education institutions to improve the quality of teaching while an increasing number of students head to universities. This is also mirrored in the current situation at RWTH (Rheinisch-Westfälische Technische Hochschule) Aachen University.

**The Current Situation – An Extra-Large Lecture in Computer Sciences** In the winter term 2011/2012 approx. 1,900 undergraduate students enrolled for mechanical engineering and industrial engineering and management at RWTH Aachen University [2]. The lecture "Computer Sciences in Mechanical Engineering 1", held by Prof. Sabina Jeschke[2] and her team of the Institute Cluster IMA/ZLW & IfU (Institute of Information Management in Mechanical Engineering (IMA), Centre for Learning and Knowledge Management (ZLW), Assoc. Institute for Management Cybernetics (IfU)), is a compulsory course in the 2nd semester. Thus, the professor and her teaching assistants are faced with approx. 1,900 listeners in the course which is composed of different teaching formats: a lecture, project work, and exercises [3]. This paper focuses on the lecture only.

Teaching at IMA/ZLW & IfU goes along with two corresponding research projects TeachING-LearnING.EU[3] and ELLI[4] (Excellent Teaching and Learning in Engineering Sciences). Both projects explore new ways of teaching in higher engineering

[1] The number of schooling years for the Abitur (German higher education entrance certificate) was reduced from 13 to 12 years. The compulsory military service was suspended as from July 1st, 2011 along with the corresponding civil service. This led to increasing numbers of students heading for universities directly after finishing secondary education and in the future even more students are expected to enter German higher education [4].

[2] Further information on the team can be found at: http://www.ima-zlw-ifu.rwth-aachen.de/institutscluster/mitarbeiter/einzelansicht/team/Sabina-Jeschke.html (last accessed October 1, 2012).

[3] More information on http://www.teaching-learning.eu (last accessed September 24, 2012).

[4] More information on http://www.elli-online.net (last accessed September 24, 2012).

education also focusing on large classes [5]. A study on lectures with more than 1,000 listeners at RWTH showed that involving students into the lecture using interactive methods is even more crucial for successful learning in large classes than in smaller classes. Hence, first experiences where gathered using interactive teaching methods such as Audience-Response-Systems (ARS)[5] where students were asked questions on their understanding of the content. Though first results have yet to be published, it can be stated that ARS resulted in increased motivation and attention of students in the class [6]

While those measures focused on integrating interactive elements into face-to-face lectures, this paper analyzes the opportunities brought about by online education. Thus, a rather new format of online education, the so called Massive Open Online Course (MOOC), is analyzed regarding its potential to improve higher engineering education especially for large classes. First, the special challenges of teaching large classes are briefly described followed by the requirements and pedagogical paradigms in higher engineering education. Finally MOOCs are introduced and categorized before dwelling on their potential for application in higher engineering education.

## 2 The Challenges of Teaching Large Classes in Higher Education

**What Number of Students Makes a Large Class?** When speaking about large classes, it is hard to define a certain number of students as differences between disciplines are predominant. Regardless of the class size, teaching large classes has a certain characteristic as Weimer in one of the first books on teaching large classes points out [7]:

> The focus is on classes in which the possibility of individual relationships between professor and student is precluded, in which not every student who wants to speak in class can be called on, and in which grading essay exams can take up every evening and weekend of the course.

While the lecture focused in this paper is provided for 1,900 students or more, the term of an "extra-large" class might be appropriate according to Stehling et al. [6].

**How to Teach Large Classes?** Teaching a large class of this size is especially challenging when it comes to integrating active and problem-based learning as required by engineering education (c.f. Sect. 3). The challenge lies in overcoming anonymity and distance between teachers and students in large classes through creating a group identity and rapport that facilitates discussion, feedback and active learning [8].

The following list summarizes some of the main tasks for teachers in order to create a favorable learning environment in a large class [8–11]:

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[5] Audience Response Systems (ARS) were developed for large classes to integrate interactive exchange between the teacher and a large number of students. Questions are answered by students either via smartphone, SMS, or an ARS device [6].

- Direct feedback and contact: by enabling personal discourse between the teacher and the students on learning goals, method, and content [10];
- Encourage class participation: by offering group work or making students contribute material;
- Promote active learning: by making lecture outlines available to students before and throughout the class, by using demonstrations or different media to keep students interested, by showing own enthusiasm for the subject, by giving "think breaks" that cut the lecture into 15–20 minute chunks, by designing the lecture around a problem-solving model, or by giving frequent assignments;
- Be organized: by offering a central website with the syllabus and external references.

Most of the methods described above are based on direct in-class interaction between teachers and students. Nevertheless, extra-large classes may still be intimidating for many students. Thus, other approaches e. g. based upon online technology shall be explored.

## 3 Didactical Approaches in Higher Engineering Education

**Shift From Teaching to Learning** Engineering education moves between two poles: hands-on experiences on one side and fundamental knowledge in natural sciences and technology on the other [12]. Student-centered learning approaches were introduced to better cater to those needs by applying activating teaching scenarios and focusing on the teacher as a coach or facilitator rather than an instructor. This is also referred to as the "shift from teaching to learning" first introduced by Barr and Tagg [13]. Thus, students are required to have a certain degree of self-directed learning competences and to take responsibility for their individual learning process. One term often referred to in this context is also "active learning".

**Active Learning** Active learning is especially hard to achieve in large classes. It has been tried to use methods such as asking challenging questions, giving students tasks to evocate reasoning and problem solving, or making students repeat learning contents in order to initiate active retrieval and reconstruction of knowledge. As studies have shown, those methods may result in higher attendance and engagement rates and better learning results [14–16]. But still methods that evocate active learning have so far rather focused on smaller classes.

**Problem-Based Learning** Learners are perceived as human beings that are intrinsically motivated to solve problems and to acquire the information and the knowledge they need to solve the problems. Therefore, a problem-based learning setting follows a guided design where students are guided through the problem-solving process beginning with a short description of the situation and the problem to be solved along with some introductory material. Their task is to figure out by themselves how the problem can be solved and to finally evaluate the solution they came up with.

Thus, problem-based learning pedagogy aims to provide students with the skills of self-assessing their work [16].

Higher engineering education heavily relies on active and problem-based learning which is especially hard to be implemented in extra-large classes. In the next section it will be analyzed whether and how an online technology such as Massive Open Online Courses (MOOCs) may help to put those learning paradigms into practice.

## 4 Massive Open Online Courses – The Virtual Solution?

### *4.1 Getting to Know MOOCs*

When defining what Massive Open Online Courses (MOOCs) are, a further deep dive into the single attributes *massive*, *open*, *online*, and *course* becomes necessary. When it comes to classify the attributes *massive* and open definitions differ according to the two main underlying didactical designs - connectivist and instructional design which will be described in detail in this section. But regardless of the didactical approach, it seems to be common sense that MOOCs at least refer to *courses* that are taught *online* on the Internet and that are open in the sense of being accessible free-of-charge for anyone [22].

**Connectivist MOOCs** According to connectivism[6] as first introduced by Siemens and Downes, learning is defined as being

> (. . .) focused on connecting specialized information sets (. . .) the connections that enable us to learn are more and more important than our current state of knowing. (. . .) Nurturing and maintaining connections is needed to facilitate continual learning. Ability to see connections between fields, ideas, and concepts is a core skill. [17].

Connectivist MOOCs are based on the principles of connectivism: autonomy, diversity, openness, and interactivity. Students in a connectivist MOOC perform four major activities (c.f. [18]):

1. *Aggregate*: Students are asked to pick and choose the content that looks interesting to them and seems to be most appropriate according to their personal learning goals from a wide range of information spilled on the Internet.
2. *Remix*: Students keep track of the information items they accessed by using any tool from lists offline on their computers to online blogs, Twitter, or the like.
3. *Repurpose*: Students describe their own understanding of the material they aggregated and remixed before and thereby create new knowledge based on already existing materials.
4. *Feed Forward*: Students share their thoughts and understanding on the Internet with other course mates and the world at large.

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[6] It has largely been discussed throughout the scientific community as to whether connectivism really states a new learning theory. A brief summary of the criticism of connectivism is provided by Siemens [19].

Connectivist MOOCs have been delivered since 2007 with the open courses of David Wiley[7] and Alec Couros mainly targeting the issue of open education itself [20]. But it was not until 2008 when George Siemens and Stephen Downes offered the online course "Connectivism and Connective Knowledge" (CCK08) that the concept of MOOCs became generally known [21]. Many other initiatives followed their example such as e. g. PLENK2010[8], eduMOOC[9], mobiMOOC[10], DS106[11], or LAK11/12[12] and until today new connectivist MOOCs keep on emerging.

In the context of connectivist MOOCs the attribute *open* rather refers to the fact that learners from different stages of learning from beginners to experts merge together in one common learning community [22]. Connectivist MOOCs so far attracted between 500 and 2,500 participants and set the range for the attribute massive at this margin though not being limited to it.

In this paper the term "cMOOC" (referring to "connectivist MOOC") is used to describe this specific MOOC format.

**Instructional MOOCs** Instructional MOOCs often follow a clear teacher-centered, instructional design according to behaviorist and cognitivist learning theory where instructors teach and students listen and accomplish quizzes or assignments. As teaching in this context is more of a one-to-many communication, discussion forums offer each student the possibility to get actively involved. The teachers themselves may answer a certain amount of questions whereas most of the questions are answered by peers around the globe (c.f. [23]). Several MOOCs emerged following the instructional course design such as the Khan Academy[13], the class on Artificial Intelligence (AI) by Stanford Professors Thrun and Norvig[14], the MITx[15]/edX[16] initiative, Coursera[17], or udacity[18] just to name the major players in the field [24].

In the context of instructional MOOCs the attribute *massive* clearly refers to an extremely high number of participants (e. g. 160,000 students in AI-class or 680,000 students in Coursera classes). The term *open* refers to the open and free-of-charge

[7] In 2007 Wiley first offered the wiki-based course "Open Ed Syllabus". The course material can be accessed at http://opencontent.org/wiki/index.php?title=Intro_Open_Ed_Syllabus (last accessed September 25, 2012).

[8] Personal Learning Environments, Networks and Knowledge 2010 (PLENK2010) http://connect.downes.ca.

[9] eduMOOC: Online Learning Today... and Tomorrow http://edumooc.wikispaces.com (last accessed September 22, 2012).

[10] Learning and training with mobile devices http://mobimooc.wikispaces.com (last accessed September 22, 2012).

[11] Digital Storytelling (DS) http://ds106.us (last accessed September 22, 2012).

[12] Learning and Knowledge Analytics (LAK) http://www.learninganalytics.net (last accessed September 22, 2012).

[13] http://www.khanacademy.org (last accessed September 22, 2012).

[14] http://www.ai-class.com (last accessed October 1, 2012).

[15] http://mitx.mit.edu (last accessed October 1, 2012).

[16] http://www.edx.org (last accessed September 22, 2012).

[17] http://www.coursera.org (last accessed September 22, 2012).

[18] http://www.udacity.com (last accessed September 22, 2012).

**Table 1** Classification of MOOCs [17, 21, 22]

| | connectivist MOOC (cMOOC) | instructional MOOC (iMOOC) |
|---|---|---|
| M(assive) | 500-2,500 students | up to 160,000 students or more |
| O(pen) | open to learners from different stages of learning from beginners to experts, no fixed set of learning materials (is gathered by students themselves), no pre-defined outcomes, no formal accreditation | pre-defined classes for different stages of expertise with corresponding learning materials, pre-defined learning outcomes, formal accreditation possible |
| | open registration, course materials free of charge, accessible and shared | |
| O(nline) | on the Internet | |
| C(ourse) | regular courses | |

access of each learner to materials and content otherwise only being available to tuition paying students [22].

This paper uses the term "iMOOCs" to refer to instructional MOOCs that follow a traditional course structure with pre-defined learning goals, materials provided and presented by a teacher, fixed assignments, and a final exam.

The analyses in this paper are restricted to those two basic types of MOOCs. Having said this, it is nevertheless clear that a variety of other initiatives emerged especially in Germany[19] that are based on the same principles but cannot be taken into consideration in order not to go beyond the scope of this paper.

**What are the Differences Between MOOCs?** Table 1 shows a classification of MOOCs into cMOOCs and iMOOCs according to the different notions of their attributes *massive* (range of number of listeners), *open* (targeted learners), and *online* (form of distribution). The attribute *course* conjointly refers to the course format as already described above.

## *4.2 How to Educate Large Classes with MOOCs?*

For analyzing the potentials of cMOOCs the courses "Openness in Education"[20] by Rory McGreal and George Siemens and "Connectivism and Connective Knowledge 2011"[21] by Steven Downes were taken into consideration. The analysis of iMOOCs is based on the courses "Introduction to Statistics" (ST101) by Sebastian Thrun and

[19] German MOOC initiatives: #ocwl11 – Open Course Workplace Learning 2011 http://ocwl11.wissensdialoge.de, OPCO11 http://blog.studiumdigitale.uni-frankfurt.de/opco11, OPCO12 http://opco12.de, iversity http://www.iversity.org, openHPI http://openhpi.de (last accessed September 12, 2012).

[20] The course can be found at http://open.mooc.ca (last accessed September 26, 2012).

[21] The course can be retrieved from http://cck11.mooc.ca (last accessed September 26, 2012).

Adam Sherwin, and "Introduction to Computer Science" (CS101) by David Evans provided by udacity[22].

The analysis focused on the requirements prescribed by higher engineering education and large class pedagogy as discussed before:

- direct feedback and contact,
- encourage class participation
- promote active and problem-based learning, and
- be organized.

Furthermore, especially for online and distance learning, the community of learners is crucial for successful learning and *community building* will, thus, be considered in the following analysis as well. In the following sections each of those elements are matched with the characteristics of cMOOCs and iMOOCs in order to analyze their potential for teaching large classes in higher engineering education.

### 4.2.1 Direct Feedback and Contact

MOOCs show different ways of integrating direct feedback and contact between teachers and students to facilitate personal discourse. Some MOOCs try to emulate one-to-one tutoring while most of the others provide different ways of direct feedback and contact.

**One-To-One Tutoring** Mainly iMOOCs emulate one-to-one tutoring with the teacher being recorded while writing down notes and explaining the content. The student is given the impression of being taught individually by the teacher. As already observed by Bloom in 1984, students tutored one-to-one perform significantly better than students who learn with conventional instruction methods [25]. Even though there have been no such studies on the effects of one-to-one tutoring in the context of MOOCs in particular, it is assumed that the emulation of one-to-one tutoring in MOOCs could have positive effects on learning and the feeling of direct contact to the teacher (c.f. [25]).

**Feedback** iMOOCs and cMOOCs use discussion boards, forums, or social media tools such as Twitter and Facebook to decrease the feeling of distance between the teacher and students and to encourage active involvement. It is assumed that students are not as hampered to discuss their questions in an online discussion forum as they would be when sitting amidst a class of 1,000 students or more. Nonetheless discussion forums with as many members as in MOOCs are threatened to become difficult to oversee. cMOOCs encourage direct feedback through comments on the learning materials gathered and remixed by each participant. Furthermore, from the

[22] Both courses can be retrieved from http://www.udacity.com/courses (last accessed September 26, 2012).

teachers point of view student feedback about the course can be gathered in forums or through social media activity helping them to improve their methods [20].

### 4.2.2 Encourage Class Participation

While in-class courses often implement group work in order to increase participation, MOOCs rely on other mechanisms such as peer learning or the integration of content contributed by students.

**Peer Learning** Peer learning happens when "... students learn with and from each other without the immediate intervention of a teacher" [26]. MOOCs heavily rely on peer learning in general since one teacher cannot interact with every single student given the large class size of MOOCs. Especially in iMOOCs the strategies of peer instruction and peer assessment play major roles. Peer instruction [27] aims to actively involve students into the lecture by integrating so called "ConcepTests" that encourage them to discuss the subject of the lecture with their peers. Peer assessment is applied when students give feedback on their peer's work or when they are required to determine and defend their own work [28]. While peer instruction is often used in iMOOCs as a method to structure the course content into demonstrations and question-and-answer sets, peer assessment takes place in forums where students assess posts, questions and answers using badges[23]. Peer learning in cMOOCs takes place through reconstructing and repurposing knowledge by peers.

**Students Contribute Course Content** Mainly used by cMOOCs the contribution of course content fosters student participation through connecting students and their individual understanding of the topics [17]. To share their materials students are asked to use the tools already available on the Internet such as blogs, tumblr[24], Diigo[25], social network sites, Twitter, and others.

### 4.2.3 Promote Active and Problem-Based Learning

Active and problem-based learning approaches put the students into the focus and try to incite them to actively take part in their learning process. iMOOCs and cMOOCs cater to those requirements in different ways.

**Active Learning** As Koller [29] shows for the case of Coursera courses (iMOOCs), active retrieval practice is used to make students actively engage with the learning material. Based on the findings on the effects of retrieval and reconstruction of

[23] First developed by the Mozilla Foundation, badges are used on the Internet as a "validated indicator of accomplishment, skill, quality or interest" [30]. They can be provided to testify the accomplishment of formal as well as informal knowledge.

[24] Tumblr is a mirco-blogging platform http://www.tumblr.com (last accessed October 3, 2012).

[25] Diigo is an online bookmarking tool http://www.diigo.com (last accessed October 3, 2012).

knowledge by Karpicke and Blunt [15] students are asked questions assessing comprehension and requiring them to make inferences on the topic. cMOOCs foster the individual's activities of collecting, sharing, and connecting knowledge and thus, achieve to integrate active learning into their courses due to the underlying principle of connectivism.

**Problem-Based Learning** As discussed above, engineering courses shall be designed around a problem-solving model which is especially hard to achieve in MOOCs. However, iMOOCs try to implement problem-based learning using examples that depict a problem with high practical relevance and by describing the appropriate problem-solving algorithm subsequently. According to Svinivki and McKeachie [16] this form can rather be classified as "case-based learning" where the students are provided with a problem and a problem-solving algorithm and are asked to critically discuss it. In contrary cMOOCs bear a higher potential to implement problem-based learning. They focus on a certain problem, give first information, and leave students the freedom to come up with own creative solutions. The teacher in this case still cannot guide each of the students individually through the process, but by providing relevant material on the topic problem-solving can be steered to certain directions. Though not having been applied to engineering topics so far, cMOOCs are likely to be adapted to engineering themes.

#### 4.2.4 Be Organized

iMOOCs are often very clearly organized using a central website where all the information on the syllabus, announcements, discussion forums or chats, and learning materials are aggregated together with all the tools the students need for learning. This provides students with a fixed framework for learning, but is rather time-consuming and expensive to dress-up. cMOOCs on the other side emphasize the effect of self-directed learning. Mostly, they also offer a central website with information on the principles of the course and a syllabus. But, in contrast to iMOOCs they do not offer a fixed set of learning materials. As Siemens also admits, cMOOCs are chaotic on purpose [20]. They constitute an open framework for learning.

#### 4.2.5 Community Building

Community building is a major prerequisite for successful learning. While learning in real-world settings automatically offers a learner community, online learning formats are faced with the challenge of building a virtual community. Svinivki and McKeachie [16] stress the negative effects of student anonymity on motivation for learning:

> Moreover, the sense of distance from the instructor, the loss of interpersonal bonds with the instructor and with other students - these diminish motivation for learning.

Thus, cMOOCs and iMOOCs alike try to use web-based tools such as forums, discussion boards or social media to enhance interaction and to create a group identity

**Table 2** Potentials of cMOOCs and iMOOCs for teaching large classes

| | cMOOCs | iMOOCs |
|---|---|---|
| Direct Feedback and Contact | – direct interaction among participants by commenting on created course materials and by connecting with other participants through social media tools | – one-to-one tutoring emulated<br>– direct feedback & conversation made available via discussion forums |
| Encourage Class Participation | – peer learning through reconstructing, repurposing and sharing knowledge by peers<br>– students contribute and share own course content | – peer learning through peer instruction and peer assessment |
| Promote Active & Problem-Based Learning | – active learning through remixing, reconstructing and sharing content<br>– course content designed around problem-solving model with teachers as guides | – quizzes to engage students in active retrieval and reconstruction of knowledge<br>– course content hard to design around problem-solving model, rather case-based learning provided |
| Be Organized | – central website with basic syllabus and links to learning resources<br>– widely distributed contents and absent curricula, no common learning goals and methods (learning might be perceived as "chaotic")<br>– open framework for learning provided<br>– use tools already available on the Internet and users are familiar with | – central website with all necessary information and learning resources<br>– fixed framework for learning provided<br>– own tools for communication (forum, chat etc.) have to be developed |
| Community Building | – virtual community using social media and discussion boards<br>– no direct meet-ups | – virtual community using social media and discussion boards<br>– real-world community through organized meet-ups |

and rapport among the course participants. The big advantage arising from the global community of MOOC participants, as Koller pinpoints, is that questions can be answered by peers at any time due to the global reach of the courses leading to a level of service no single teacher is able to provide [29]. Lately, udacity introduced personal meet-ups to encourage face-to-face interaction among students and to add personal and peer teaching in groups to their courses[26].

### 4.2.6 Summary

Table 2 summarizes the potentials of cMOOCs and iMOOCs for teaching large classes in higher engineering education.

## 5 Conclusion

As shown above the two major types of MOOCs constitute two fundamentally different learning approaches. While connectivist MOOCs focus on a student-centered approach, instructional MOOCs are rather teacher-centered. Both types of MOOCs bear a high potential for being introduced into curricula of higher engineering education. Until recently, iMOOCs have mostly been applied to engineering topics while cMOOCs focus on humanities and science in general. Moreover, iMOOCs lag behind cMOOCs in terms of active and problem-based learning being a basic

[26] Meet-ups are organized through a separate platform http://www.meetup.com/Udacity/ (last accessed September 19, 2012).

requirement for good engineering education. Both types of MOOCs require students to have a high level of self-learning competences in order to lead to successful learning. cMOOCs are even more demanding in this respect than iMOOCs due to a total lack of a course outline or guidance throughout the course.

A major weakness of iMOOCs is that they hardly achieve to implement problem-based learning. In contrast, cMOOCs highly encourage problem-based learning. Hence, it is suggested to analyze in a next step whether a combination of both models can be applicable and if so, how an according course design could look like.

Regardless, of this major drawback current iMOOCs can definitely be applied to teach fundamentals in engineering education as is shown by recent courses from Coursera, udacity, or edX. By teaching fundamentals one of the basic pillars engineering competence rests upon can be supported [12]. As statistics show, early drop-outs in higher engineering education are often caused by insufficient basic knowledge in natural sciences and technology. Thus, students struggle in the first semesters to catch up the fundamentals they failed to acquire in secondary education [1]. Hence, by using encouraging methods to teach fundamentals in higher engineering education, the motivation of students to stick to the course might be increased having a positive effect on lowering drop-out rates.

In a next step an integrated concept will be developed for the lecture "Computer Science in Mechanical Engineering 1" that combines the elements mentioned above. Therefore, general advantages and disadvantages of MOOCs will also have to be taken into consideration. The good thing about MOOCs is that just a few technical requirements are necessary such as a computer and Internet access and that they are open to anyone being sufficiently equipped. The work can be shared with others, and students around the world can benefit from each other and outstanding professors. On the other side, technical difficulties can impede the learning process, the learner's preferences for traditional learning formats may not be satisfied, and higher education institutions might not integrate them into curricula as they do not come along formal accreditation (c.f. [31, 32]).

**Future Research** There are several topics that have to be dwelled upon as research on MOOCs has just recently emerged. Certainly some interesting questions are to be answered e. g. on the effects of one-to-one tutoring in MOOCs, the consequences of class sizes for activities in discussion forums, peer learning and community building processes in online media, and the implementation of problem-based learning with a MOOC. Moreover, the integration of MOOCs into the higher education system might result in a redefinition of the role of the university. What are the consequences for higher education institutions, teaching and research staff as well as students when a few outstanding professors reach large amounts of students? Questions on the standardization of education will have to be answered as well as on financing models, forms of accreditation, or legal issues.

In addition, the use of technology in education leads to gathering big data on learning patterns and habits of the new generation of learners, the digital natives, being a rich resource for further research. Techniques from data mining, machine learning or natural language processing are adapted to the needs of learning analytics.

As indicated by the Horizon Report 2012 [33], learning analytics will be one of the central topics for research on education within the next five years. This will lead to a shift from a hypotheses-driven approach to data-driven research on education and learning. Thus, the foundations to gather data are to be laid already today. MOOCs are one important step in this direction.

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# International Exchange in Higher Engineering Education – A Representative Survey on International Mobility of Engineering Students

**Ute Heinze, Ursula Bach, René Vossen and Sabina Jeschke**

**Abstract** The attitude of German engineering students towards spending a certain period of time abroad is highly ambivalent. Although German engineering students assume that international experience is a key competence and a career-enhancing qualification, outbound mobility (referring to the number of students who leave Germany to another country for the purpose of study or a traineeship) in higher engineering education lies below average compared to other disciplines. One reason frequently listed by students is the intensive workload in engineering sciences hampering their opportunities to go abroad as well as difficult recognition procedures of study credits accomplished abroad. Statistics show that the changes brought about by the Bologna Reform (initiated in 1999 to align European higher education and to establish a common credit transfer system) did not result in increased student mobility throughout Europe. It rather resulted in less flexible curricula leaving students not enough time for spending a certain part of their studies abroad. This paper analyzes the current situation of international student mobility in German higher engineering education especially focusing on outbound mobility. It is based on the results of a survey carried out among approx. 35,000 students at one of Germany's most renowned technical universities. The study deals with the motivation and the obstacles faced by engineering students aiming at integrating international exchange periods into their curricula. Therefore, an anonymous wide ranging survey was distributed among all students at the above mentioned university. Topics such as financial issues, the recognition of credit points, and career advice services influencing their decision in or not in favor of an international exchange are investigated among other aspects. The results of the survey are finally summarized together with derived measures to increase the participation of engineering students in international exchange programs.

**Keywords** International Student Mobility · Inbound · Outbound · Engineering · Education · Curricula Development · Intercultural Competences

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# 1 Introduction

Nowadays, intercultural competences and social skills are inevitable for a successful engineering career because they play a significant role in professional profiles of engineers and will do so even more in the future. Those competences can only be gathered through international exchange. Due to the progressing globalization companies do no longer operate only on local but on global markets. Thus, especially engineering should not be limited by national borders. Therefore students have to be prepared to face the challenges connected with globalized markets [1].

Nevertheless, the number of students in engineering science who leave Germany to another country for the purpose of study or traineeship (referred to as "outbound mobility" [2–4]) is distinctly below average compared to other disciplines [5]. Statistics show that the goals of the Bologna Reform, whose key aim was the unification of European higher education to boost international mobility by establishing a common credit transfer system, were not obtained satisfactorily [2]. The reform focused on structural changes to increase student mobility throughout Europe as a central goal. On the Ministerial Conference 2009 in Leuven and Louvain-la-Neuve the European Ministers of Education and Research set the aim that until 2020 20 % of European students should have lived and worked abroad [6, 7]. On the Bologna conferences in Budapest and Vienna in 2010 it became clear that this goal will not be accomplished [8, 9].

Especially engineering students tend to be less mobile as several studies indicate [2, 10, 11]. In order to take a deeper look at the motivational factors and obstacles engineering students face when planning international exchange periods, a survey was carried out among approx. 33,000 students at Rheinisch-Westfälische Technische Hochschule (RWTH) Aachen University in November 2012.

The survey was performed by the institute cluster IMA/ZLW & IfU – Institute of Information Management in Mechanical Engineering (IMA), Center for Learning and Knowledge Management (ZLW), Associated Institute for Management Cybernetics e. V. (IfU) in cooperation with RWTH's International Office. Its aim was to investigate motivational factors and obstacles students face in different planning and realization stages of a foreign exchange. The anonymous and wide ranging survey covers topics such as financial issues, the recognition of credits, and career advice services among other personal factors influencing a decision on international exchange.

The present paper introduces current studies related to the topic of international mobility of engineering students, and describes the method as well as the results of the RWTH survey and puts them into relation to major studies representing the current state of the art in the research on international student mobility: the study on international mobility and study-related exchanges of German students carried out by Heublein and Hutzsch [5] of Hochschulinformations GmbH (HIS) in 2009 and 2011, the annual report "Wissenschaft weltoffen" performed by the German Academic Exchange Service (DAAD) [2], and the 19th Social Survey of the Deutsches Studentenwerk (German National Association for Student Affairs) on the economic and social conditions of student life in Germany in 2009 [11].

## 2 Current Studies on International Mobility of Engineering Students

Several studies take a deeper look at outbound mobility of German students. According to data from the German Academic Exchange Service (DAAD) and the Higher Education Information System Institute (HIS) [12] as well as the German Federal Statistical Office [13] 64 out of 1000 students from German higher education institutions pursued a study-related exchange in 2010. These numbers include those students who reside abroad on a temporary basis as well as those who work towards a degree from a foreign higher education institution. Compared to the mobility numbers of the past decade, an increase in outbound mobile students can be observed as is shown in Fig. 1.

When looking at mobility rates for different subject groups, data are available for example from the European exchange program ERASMUS, as shown in Fig. 2.

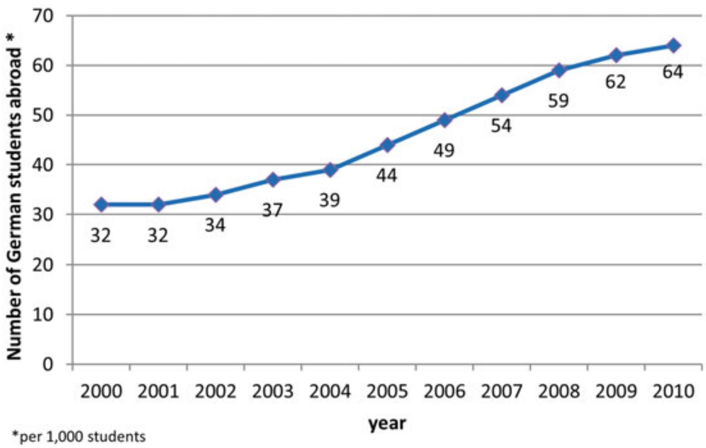


**Fig. 1** Development of mobility rate of German students from 2000–2010, per 1000 students [13]

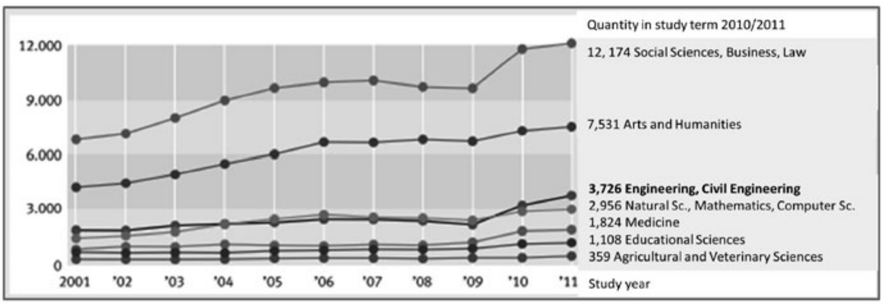


**Fig. 2** German ERASMUS students by subject group [12]

**Table 1** Rate of mobile students, by discipline in % [11]

| Disciplines | Year | | | | | |
|---|---|---|---|---|---|---|
| | 1994 | 1997 | 2000 | 2003 | 2006 | 2009 |
| Engineering science | 2 | 3 | 4 | 4 | 3 | 4 |
| Language and cultural studies | 12 | 12 | 13 | 12 | 12 | 12 |
| Maths/natural science | 4 | 5 | 4 | 5 | 5 | 5 |
| Medicine/health | 4 | 5 | 5 | 7 | 6 | 5 |
| Law and business studies | 5 | 8 | 9 | 8 | 9 | 11 |
| Social/education science, psychology | 2 | 4 | 4 | 5 | 6 | 8 |

Out of 30,274 German ERASMUS exchange students, approx. 40 % (12,174) came from the social sciences, business and economy, or law, approx. 25 % (7531) from the humanities and liberal arts, approx. 12 % (3726) from engineering sciences and approx. 9 % (2956) from natural sciences, mathematics and computer science in the study term 2010/2011 [12]. Apparently, students from the subject groups of science, technology, engineering and mathematics (STEM fields) lag behind their counterparts from other subjects in terms of study-related international mobility. Certainly, the data presented here might be biased due to the mere focus only on one single program, the ERASMUS program. It may be the case that the program itself mainly attracts students from other subjects than the STEM fields through its funding scheme or program design. EU official statistics show that approx. 60 % of ERASMUS funded students in 2010 and 2011 were women [14]. As in Germany the majority of students in STEM fields are male, they might participate in ERASMUS exchange to a fewer degree and thus do not appear in the official statistics which results in generally lower exchange numbers for students in STEM fields.

Nevertheless, other studies such as the 19th Social Survey of the Deutsches Studentenwerk (German National Association for Student Affairs) on the economic and social conditions of student life in Germany in 2009 [11] or the study of Heublein and Hutzsch [5] show similar results and tendencies.

Even though the mobility rates among students from STEM fields are comparatively low, their development over the last years is steeper than in other disciplines as Table 1 shows.

Since 1994 mobility rates among students of language and cultural studies stayed constantly at a high level (1994: 12 %, 2000: 13 %, 2009: 12 %) whereas students in engineering science became a lot more mobile over the same timespan where mobility rates nearly doubled between 1994 (2 %) and 2009 (4 %). [11]

Heublein and Hutzsch [5] also discovered differences in mobility levels according to degree programs as Fig. 3 shows.

Students enrolled in the traditional German degree programs that were in place before the Bologna Reform such as the magister and diploma degrees show a higher mobility rate than bachelor students. They argue that this is mostly due to the higher average age and number of study semesters as well as the lacking enrollment of

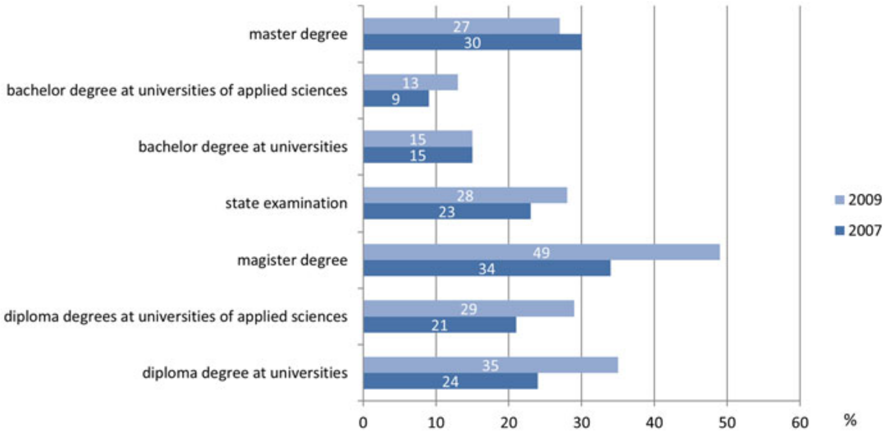


**Fig. 3** Study-related international exchange periods of German students according to degree program, in % [5]

new students in the traditional programs. Those numbers suggest that new degree programs seem to hamper international mobility.

Just a few studies dwell on the motivational factors and obstacles students face when planning and accomplishing international exchange phases. According to numbers from DAAD [2], HIS [5] and the Ministry of Innovation, Science and Research of the German state of North-Rhine Westphalia [15] the following obstacles are often reported:

- problems in the recognition process of credits accomplished abroad,
- time lost in the overall course of studies,
- problems with harmonizing the international exchange phase with the study requirements of the home institution, and
- financial problems.

As already Heublein et al. [16] argue further studies on student motivation for international exchange hardly exist. Therefore, the present survey focuses the motivational factors and obstacles for international exchange periods at RWTH Aachen University in further detail.

## 3 Method

The survey was carried out as an online questionnaire in order to reach as many students as possible and was distributed among 33,003 students that gained their higher education entrance qualification at a German school in Germany or abroad (so called 'Bildungsinlaender students'). The sample accounts to $N = 3218$ completely answered questionnaires which results in a return rate of 9.75 %. It was distributed over a period of 4 weeks from November 5–30, 2012 using email notification and an email reminder once after the first 2 weeks in order to remind students to participate.

The sample was divided through filter questions into five parts in order to provide students in different planning or realization stages of their exchange periods with tailored questions.

- part 1: students who were abroad and were back in Germany at the time of the survey
- part 2: students who were abroad at the time of the survey
- part 3: students who were still in Germany but planning an exchange period at the time of the survey
- part 4: students who had planned an exchange period before, but finally did not realize it
- part 5: students who were not planning any exchange period at all

Furthermore, the questions were divided into nine thematic blocks:

- block 1: demographic data
- block 2: study related data
- block 3: information on the exchange
- block 4: motivation and evaluation of exchange
- block 5: obstacles
- block 6: experiences and problems
- block 7: financing of exchange
- block 8: recognition of study credits
- block 9: used sources of information

The questions of blocks 1, 2, and 8 were mainly composed of single or multiple choice questions, drop-down lists or entry fields. Question blocks 3, 4, 5, 6, and 7 also used the above mentioned question types added by questions where participants were asked to rate their answer tendency according to a specific statement on a scale ranging from 1 “does not apply at all” through to 6 “applies fully”.

# 4 Description of the Sample

## *4.1 Demographic Data*

A majority of 61.5 % of students that took part in the survey were male with an average age of 23.44 years. 3, 064 participants were German (approx. 95 %), 16 Chinese (approx. 0.5 %), 15 Turkish (approx. 0.5 %) and 10 Russian (approx. 0.3 %). 97.4 % of the participants gained their higher education entrance qualification in Germany.

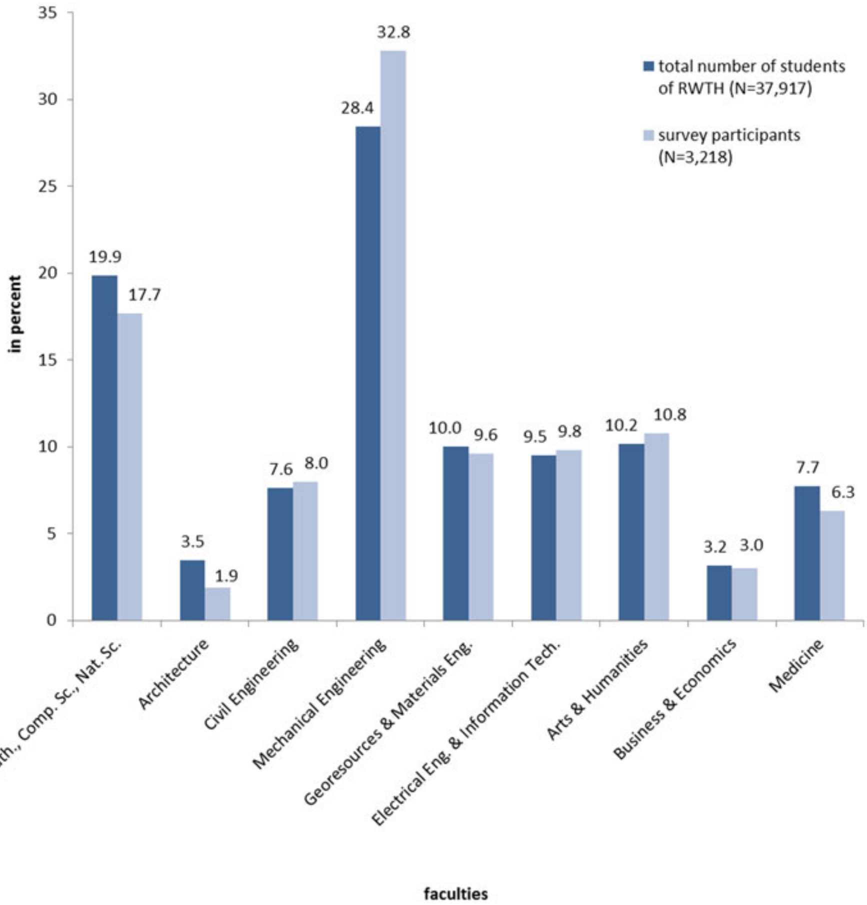


**Fig. 4** Distribution of participants among university faculties, in % [17]

## *4.2 Study Related Data*

Figure 4 shows the distribution of survey participants among the different faculties of the university comparing the total number of students at RWTH Aachen University in the winter term 2012/2013 [17].

It shows that the participants of the survey were almost evenly distributed among faculties compared to the general distribution of all RWTH students. Thus, any bias in the distribution of survey participants cannot be observed producing well balanced data resource.

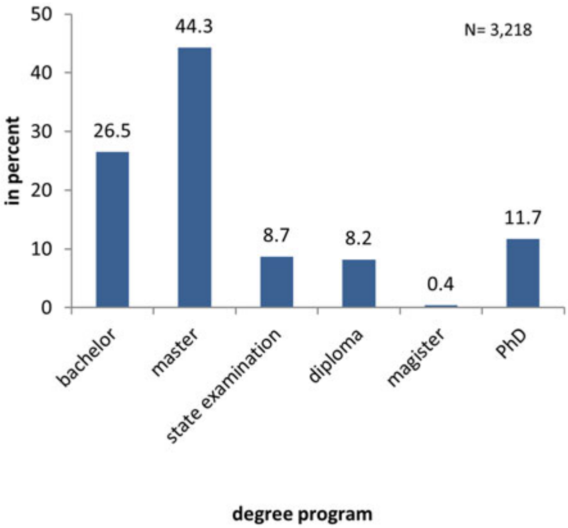


**Fig. 5** Repartition of degrees among survey participants, in %

## *4.3 Repartition of Degrees*

The survey participants worked on different academic degrees as Fig. 5 depicts.

The majority of the survey participants were enrolled in the post Bologna degree programs with 44.3 % master and 26.5 % bachelor students. Together 17.3 % pursued a traditional degree program such as diploma, magister, or state examination and 11.7 % were enrolled as PhD students.

## *4.4 International Experiences*

A clear majority of 50.7 % of all survey participants had never gathered any experiences abroad before starting their higher education programs. While 27.8 % gathered international experiences through one exchange, 20.4 % pursued two or more exchanges before entering university as is demonstrated in Fig. 6.

With 66.3 % two-thirds of the survey participants gathered international experiences before studying, mostly through student exchanges at high school with 31.8 % or language courses with 12.4 % as is shown in Fig. 7.

The survey participants were in different planning and realization stages of their exchange or were not planning to go abroad at all as Fig. 8 shows.

The sample can be divided into 3 groups in terms of international experiences gathered:

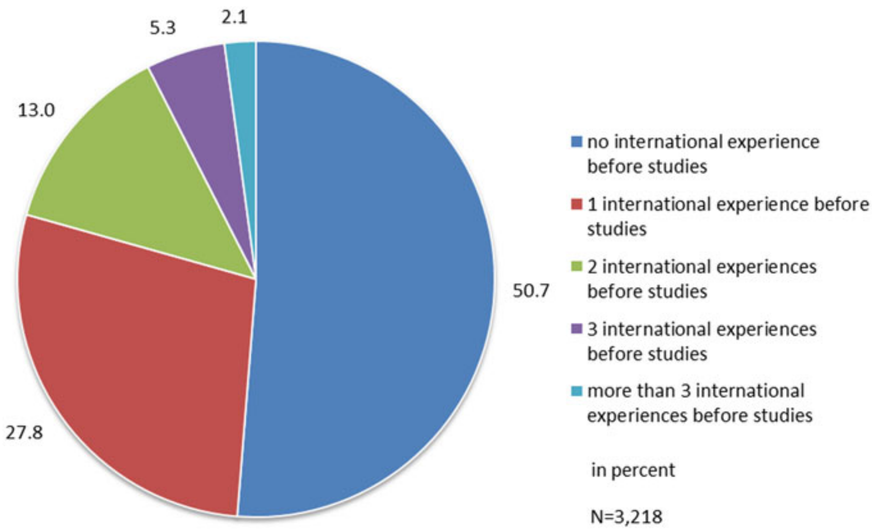


**Fig. 6** International experiences before studies, in %

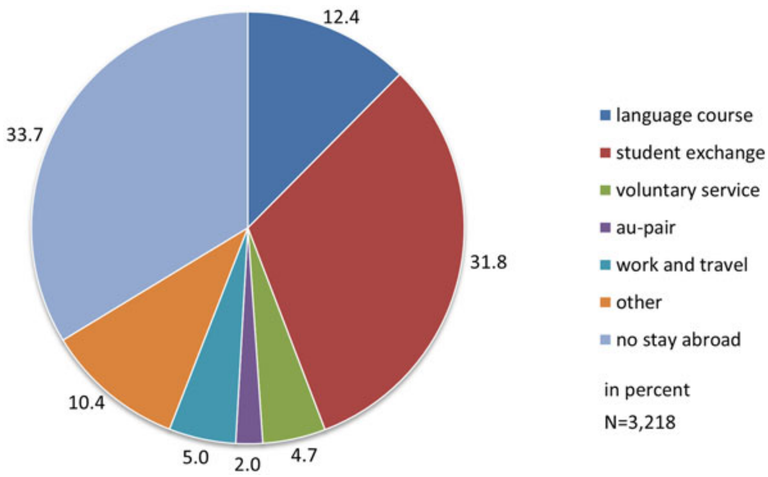


**Fig. 7** Types of international experiences of survey participants before studies, in %

- group A: students with international experiences (those who were abroad and are currently abroad)
- group B: students currently planning an exchange
- group C: students without any international experiences (those who had planned an exchange, but cancelled it and those who do not plan any exchange)

With 34.4 % more than one-third of the sample can be attributed to group A. 33.2 % of students belong to group B and thus actually plan to go abroad during their studies.

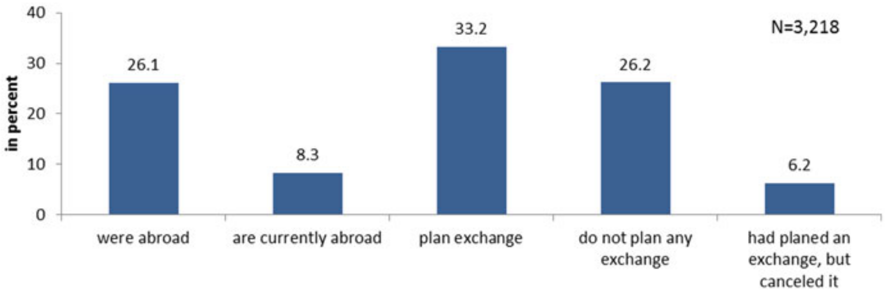


**Fig. 8** Planning and realization stages of survey participants, in %

All together 32.4 % of the survey participants belong to group C and have not gathered any international experiences whereas 6.2 % had originally planned to undertake an exchange and 26.2 % did not plan to go abroad at all. Thus, the sample is well balanced in terms of international experiences of the survey participants.

Those characteristics of the sample can also be found in similar studies. According to Heublein and Hutzsch [5], approx. one-third of all students plan an international exchange during their studies, 20 % are not decided yet, and 35 % do not envisage going abroad at all. A third of those who went abroad even plan another exchange period.

# 5 Results of the Survey

## *5.1 Mobility According to Disciplines*

When comparing mobility of engineers with students of other disciplines, the survey did not discover any specific differences. The participants from the engineering faculties of Mathematics, Computer Science and Natural Sciences, Civil and Mechanical Engineering, Georesources and Material Engineering as well as Electrical Engineering and Information Technology ('engineer') were compared to those of the faculties of Architecture, Arts and Humanities, Business and Economics and Medicine ('no engineer').

Those participants who had already been abroad or were abroad at the time of the survey were attributed to the variable 'was/is abroad', all others to the variable 'has not been abroad'. Table 2 shows the frequency distribution among the tested variables.

A Pearson's chi-squared test was performed on the two nominal variables 'engineer' or 'no engineer' and 'has not been abroad' or 'was/is abroad'. The null hypothesis ($H_0$) on the relationship between the two variables was tested and the following results calculated ($\chi^2$: chi-squared value, $p$: probability value):
$\chi^2\ (1, N = 3218) = 0.90; p = 0.05$

**Table 2** Contingency table for mobility & engineering students, in frequency of answers

| | Was/is abroad | Has not been abroad | Total |
|---|---|---|---|
| *Engineer* | 873 | 1634 | 2507 |
| *No engineer* | 234 | 477 | 711 |
| *Total* | 1107 | 2111 | 3218 |

The results fail to reject the null hypothesis, which means that there is no significant difference in mobility affinity between the disciplines. Thus, engineering students are not less mobile than other students that took part in the RWTH survey.

These results are contrary to the numbers introduced above showing that engineering students are mostly less mobile than students from other disciplines such as the social sciences, business and economics, or arts and humanities [12]. While those numbers rely on studies with a much broader data background, the present survey only shows the picture of RWTH Aachen University. The reasons for these deviant results can only be speculated. Most certainly, the bigger engineering faculties in terms of student numbers dispose of better structures than the smaller faculties such as the arts and humanities faculty by providing i. e. explicit coordinators for international relations that encourage their students to undertake international exchanges [18]. Furthermore, RWTH has installed double degree programs [19] with partner universities in China, Japan and France explicitly for engineers and students from STEM fields which is also reflected in the higher exchange numbers among those students. Moreover, RWTH has built a unique reputation also on international level due to the fact that it succeeded for the second time within the Excellence Initiative of the German federal and state governments, and thus consolidated its leading position among German universities [20]. This led to more university partnerships especially in the highly requested target regions such as the US, Spain or Sweden (c.f. *5.3 Countries of destination*). Together with the English-taught master's degree courses in computer science, mechanical and electrical engineering as well as geophysics not only the incoming numbers of international students might have been increased but also national students that are more aware of the positive effects of international experiences for their later careers might have been encouraged to go abroad. Last but not least, exchange numbers among the RWTH engineering students might have increased due to close links of the respective faculties to industry partners resulting in a wide range of industry internships abroad.

Apart from those measures a certain selection effect within the survey due to imperfect randomization of the sample cannot be ruled out. It may be the case that rather mobility-prone students took part in the survey and thus influenced the results accordingly.

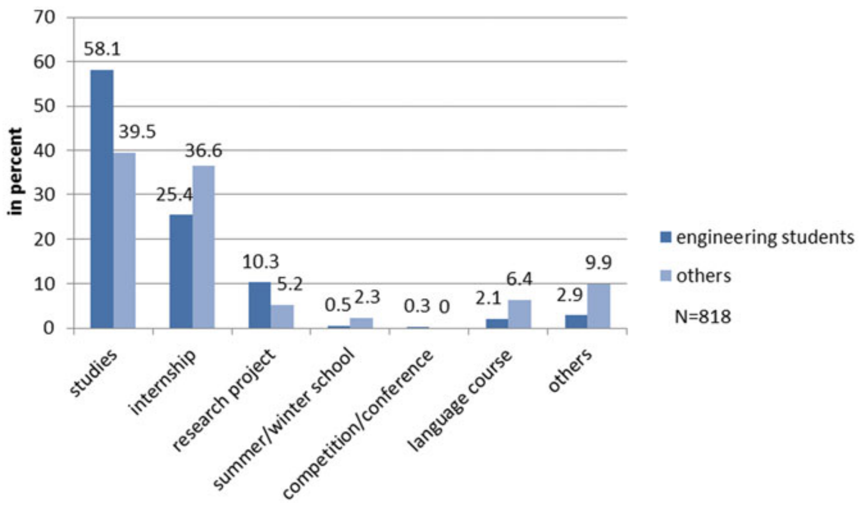


**Fig. 9** Prioritized types of exchange by engineering students and others, in %

**Table 3** Rate of mobile students with study-related activities, by discipline in % [11]

| Disciplines | Studies | | Internship | | Language course | | Other | |
|---|---|---|---|---|---|---|---|---|
| | 06 | 09 | 06 | 09 | 06 | 09 | 06 | 09 |
| Engineering s. | 3 | 4 | 6 | 7 | 2 | 1 | 1 | 1 |
| Language and cultural studies | 12 | 12 | 9 | 8 | 7 | 6 | 4 | 4 |
| Maths/nat. s. | 5 | 5 | 5 | 5 | 2 | 1 | 2 | 2 |
| Medicine/health | 6 | 5 | 18 | 16 | 3 | 2 | 3 | 2 |
| Law and business studies | 9 | 11 | 9 | 7 | 5 | 3 | 1 | 1 |
| Social/education s. psychology | 6 | 8 | 7 | 7 | 3 | 3 | 2 | 2 |

## *5.2 Types and Duration of Exchange*

Different types of foreign exchange seem to be commonly chosen by students from the different disciplines. As the following figures show the mobility preferences of engineering students differ significantly from other students. When asked to rate the three most important types of exchange, they answered as follows (Fig. 9).

Hence, studies and internships are highly and almost evenly prioritized among all students whereas engineering students prefer to pursue their studies more than an internship abroad.

This is contrary to the numbers of the Deutsches Studentenwerk. According to them, students of language and cultural studies often chose to pursue their studies abroad whereas engineering students prefer to take up internships in the respective country of destination as is shown in Table 3 [11].

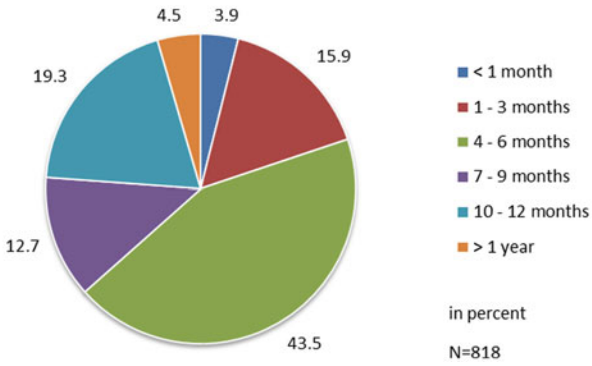


**Fig. 10** Duration of international exchanges, in %

The difference in results compared to the RWTH survey may be attributed to a wide ranging network of partnering universities rather than contacts to industry partners. Presumably, students tend to take advantage of already existing networks rather than organizing an industry internship themselves. Regarding the duration of the exchange most of the students that were abroad before and that were abroad at the time of the survey chose a period of 4–6 months (43.5 %) which perfectly fits into one study term. 19.9 % of all participants pursued a 3-month exchange or shorter. 19.3 % preferred to stay abroad for 10–12 months. On average students went abroad in their 7th semester (M = 7.04, SD = 3.02) (Fig. 10).

This also corresponds with the numbers of Heublein and Hutzsch [5]. While engineering students tend to pursue short-term stays abroad such as internships, students in the humanities often organize long-term studies. The average international exchange lasted for approximately 6 months. Only 8 % of students stayed longer than 12 months abroad. While studies lasted 6 months, internships lasted 3 months on average.

Just very few curricula integrate mandatory exchange periods. The majority of 96.2 % of all RWTH survey participants answered that exchange periods were not mandatory. When asked whether those periods shall be made mandatory the majority of 58.3 % declined it. Thus, the students seem to appreciate that international exchange periods have to be self-organized and can be integrated at a time of their choice into their studies. 44.2 % of participants took semesters off in order to go abroad and accepted a related extension of the overall study time (60.6 %).

## *5.3 Countries of Destination*

The following table shows the five most popular countries of destination for international exchange among the survey participants separately for engineers and other fellow students (Table 4).

**Table 4** Most popular countries of destination among survey participants

| Rank | Engineers | Others |
|---|---|---|
| 1 | US | Spain |
| 2 | Spain | France |
| 3 | Sweden | US |
| 4 | UK | UK |
| 5 | France | Italy |

**Table 5** German students abroad in 2008, by country of destination, in % [2]

| Destinations | Quantity | Amount |
|---|---|---|
| Austria | 20.019 | 19,6 |
| The Netherlands | 18.972 | 18,6 |
| Great Britain | 12.895 | 12,6 |
| Switzerland | 11.005 | 10,8 |
| USA | 9.679 | 9,5 |
| France | 6.071 | 5,9 |
| Australia | 3.418 | 3,3 |
| Sweden | 3.400 | 3,3 |

Hence, the most popular countries are almost evenly distributed among disciplines. While engineers tend to prefer the US more than the European countries, students of other disciplines prefer European countries slightly more than the US.

Also the language plays a major role in choosing a country of destination. 61.6 % of the participants used the respective language of the country during their studies. Thus, the languages learned at school such as the European languages English, French, or Spanish or the ones being close to German such as Swedish are preferred.

The tendency of a clear preference of European countries is also mirrored by the numbers of DAAD [2], while different countries of destination were most popular in different disciplines: 40 % of German bachelor students went to the Netherlands, 37 % of German PhD students abroad enrolled in Switzerland and 61 % of students with other degrees (such as diploma or master) took up studies in Austria. As is shown in Table 5 the neighboring countries seem to be most attractive to German students with Austria and the Netherlands being the most visited countries as well as the UK and the US as Anglophone countries.

Also Heublein and Hutzsch [5] show that the most popular countries of destination of German students such as the UK, France, and Spain were situated in Western Europe. Only 12 % went to the US or Canada, 11 % to Eastern Europe, 11 % to Asia, and 7 % to Latin America or Africa.

## *5.4 Experiences of Exchange*

When asking those who are currently abroad or who have already finished their international exchange on the experiences their gathered the following picture emerges.

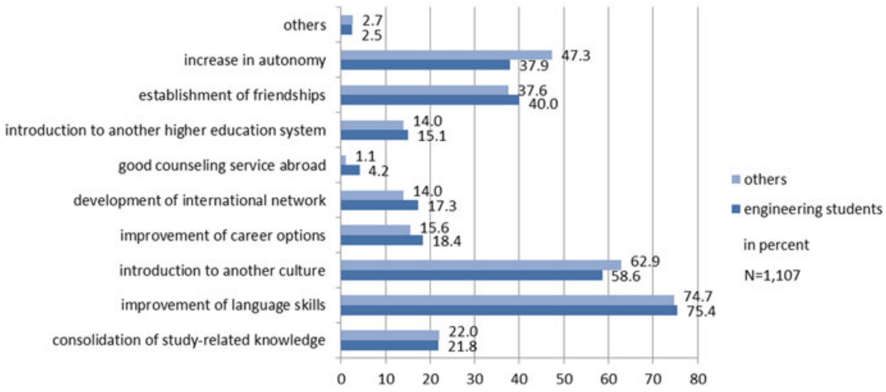


**Fig. 11** Experiences during exchange, by discipline in % (multiple answers possible)

Across disciplines positive experiences were gathered in developing language skills, getting to know a new culture and friends and an increased autonomy (Fig. 11).

While non-engineers seem to rate the introduction to another culture and an increase in autonomy as more relevant than engineers, they seem to have gathered better experiences with good counseling services abroad or the improvement of career options.

Heublein and Hutzsch [5] also confirm that students report to gather rather positive experiences abroad regardless of the country of destination. Eighty-one percent of students were able to deal with the new culture without any problems and report of having had the feeling of being integrated into society. This highly corresponds with good language skills and can also be attributed to a good preparation leaving students with appropriate expectations for international exchange.

## 5.5 *Problems of Exchange*

Most problems were reported concerning financing and the search for accommodation. While engineering students seem to have fewer problems with financing their studies abroad, they report more problems with communicating in the respective foreign language, in contacting locals or in dealing with the requirements of studies. 20–25 % of students reported to having had no problems at all (Fig. 12).

Heublein and Hutzsch [5] report that approximately one quarter of the students had difficulties in financing their studies as well as criticized a lack of support by their sending university. Fewer problems are reported concerning the requirements of studies abroad and the recognition process. Only 16 % referred to problems in the search for an accommodation.

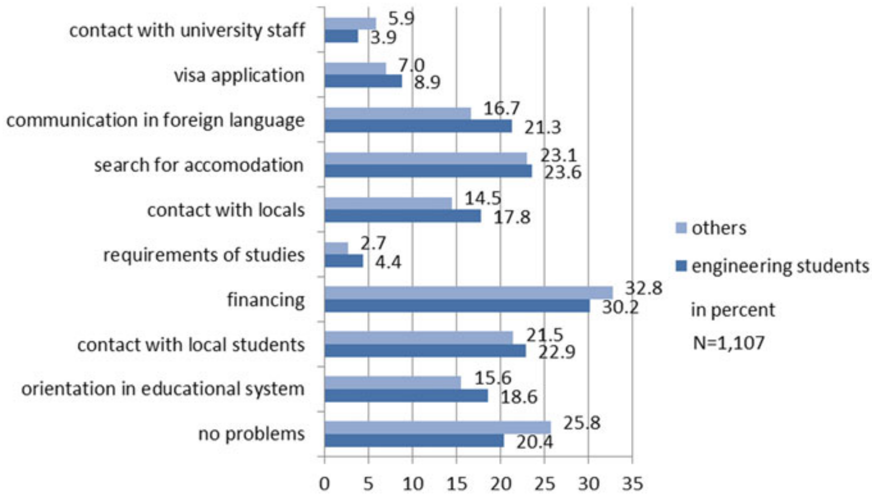


**Fig. 12** Problems during exchange, by discipline in %

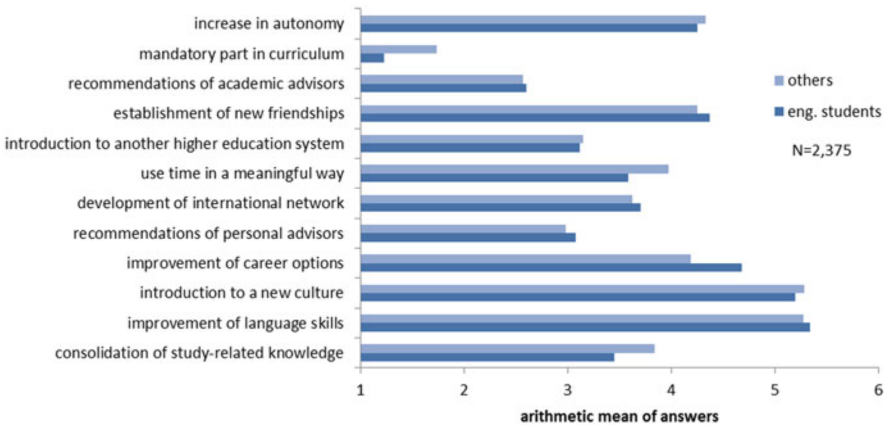


**Fig. 13** Motivational factors for planning an international exchange, by discipline

## *5.6 Motivation for Exchange*

The participants were also asked to rate a pre-defined set of motivational factors on a range between 1 (no motivational factor) to 6 (high motivational factor). The following tendencies can be observed in Fig. 13.

As the figure shows there seems to be a good match between motivational factors influencing the decision in the planning phase and the actually gathered experiences during the stay abroad (c.f. Fig. 11).There is a slight difference between the estimation of improved career options before and during the exchange period. While in the

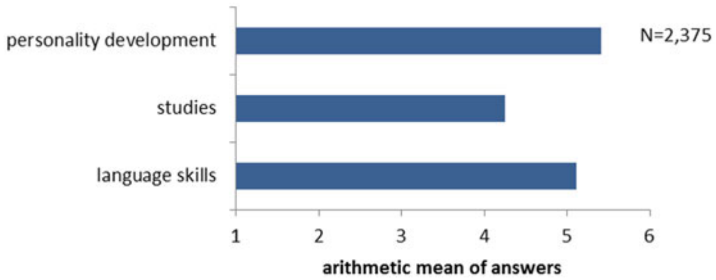


**Fig. 14** Evaluation of positive effects of exchange

planning phase students tend to estimate a high influence of international experiences on their professional career, they rate it rather low during their stay abroad. The most important motivational factors across disciplines seem to be the improvement of language skills and the introduction to a new culture along with the establishment of new friendships and an increase in autonomy. This corresponds with the positive experiences students gather when being abroad (c.f. *5.4 Experiences of exchange*).

Differences between engineers and students of other subjects can be observed at the factors 'mandatory part in curriculum', 'use time in a meaningful way', 'improvement of career options' and 'consolidation of study-related knowledge'. While exchange periods are often mandatory in curricula of non-engineers, it is not common in engineering sciences. Engineers tend to be more motivated by improved career options and less motivated through using time in meaningful way, or by consolidating their study-related knowledge than other disciplines.

When asked to evaluate their exchange participants scaled its effects on their personal development and the improvement of their foreign language skills higher than on their studies as is shown in Fig. 14.

Heublein and Hutzsch [5] also point to motivational factors for international exchange. Most of the students focus on improving social as well as language skills and on gathering experiences in another culture. Seventy-one percent perceive an international exchange as being career-enhancing. Only half of the students aim to improve their discipline-specific knowledge. Forty-five percent plan to work abroad in their profession and thus try to gather international experiences already during their studies. Figure 15 summarizes the motivational factors of students to go abroad.

## *5.7 Obstacles for Exchange*

The most important obstacles across disciplines are time pressure, financial problems, and too few exchange opportunities. Financial problems seem to be more severe for other students while engineering students rated those problems less relevant. Participants did not see any special problems imposed by the fear of the unknown or

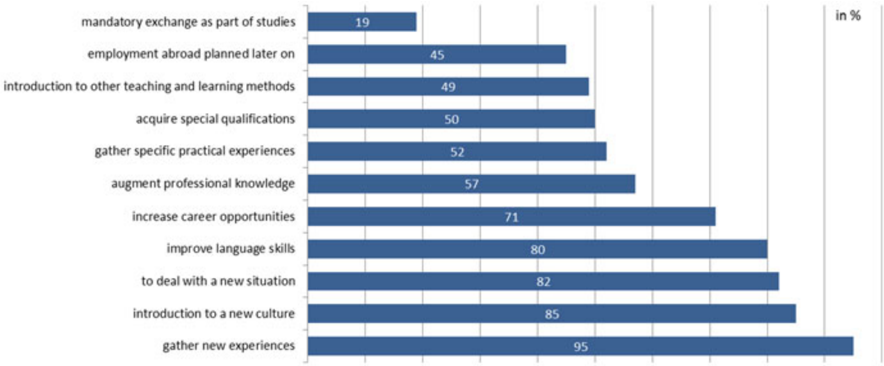


**Fig. 15** Reasons for study-related exchange, answers on a scale from '1 = not important at all' to '5 = very important', in % [21]

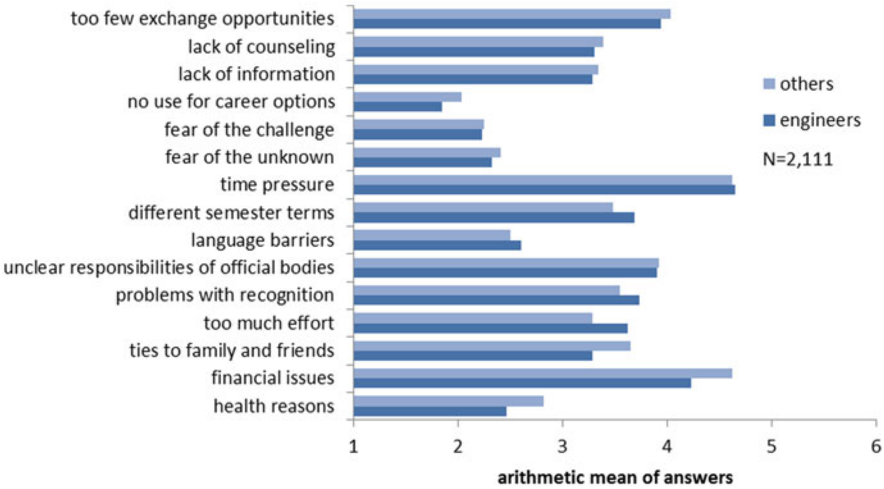


**Fig. 16** Obstacles for international exchange, by discipline

the challenge of going abroad. They also rated the fact of an international exchange being a problem for their career as rather low, as is summarized in Fig. 16.

According to Heublein and Hutzsch [5] approx. 10 % of all students fail to realize an international exchange period regardless of their specific course of studies. The most evident reasons were problems with financing the exchange (49 %), a lack of support by their home university (45 %), low compatibility with the requirements of their studies (43 %), or a loss of time (39 %). Only 33 % refer to problems in the recognition process.

Apparently, the participants of the RWTH survey seem to feel an extraordinarily high time pressure. This may be due to strict curricula leaving not enough time to integrate an international exchange.

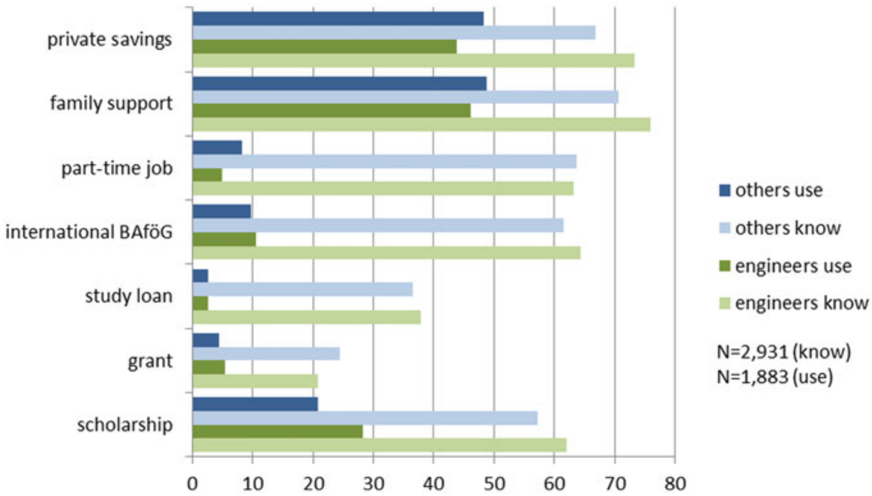


**Fig. 17** Level of information and use of financing for exchange, by discipline in %

## 5.8 *Financing of Exchange*

Most of the students take advantage of their own savings, their parents' financial support, or scholarships to go abroad. Engineering students tend to use scholarships to finance their exchange more than other students while the others rely more on private savings and family support. Only 10.3 % receive state-funded grants that support their studies in Germany (international BAföG) also abroad. Generally students are very well informed about possible ways of financing their international exchange, but use only few of their opportunities as Fig. 17 demonstrates.

## 5.9 *Recognition of Study Credits*

Most of the students report not to have had any problems in the recognition process at all. Of those problems that occurred, most frequently the duration of the recognition process was criticized along with different syllabi and problems with the conversion of acquired credits. Obviously, engineering students face bigger problems in all of the stages of the recognition process as demonstrated in Fig. 18. Thus, special measures to tackle those problems for engineers are necessary.

Heublein and Hutzsch as well as the Deutsches Studentenwerk confirm these tendencies. Acccording to Heublein and Hutzsch only a fifth of all students face problems within the recognition process. Whereas the Deutsches Studentenwerk [11] points out that students in the planning phase of an international exchange tend to be hampered by the prospect of having problems in the recognition process more than the problem really occurs later on.

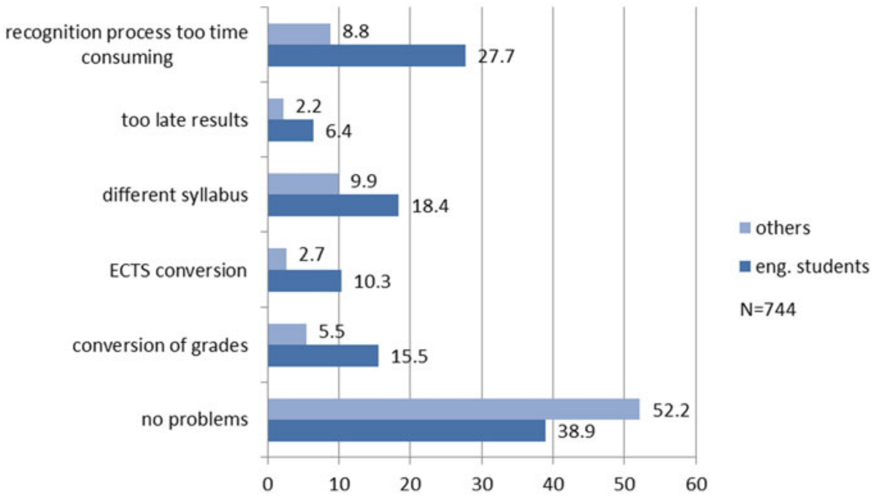


**Fig. 18** Problems in recognition process, by discipline in %

## 6 Summary and Conclusion

The survey among approx. 33,000 RWTH students has led to the following key findings.

- The survey could not confirm the tendency of low mobility among engineering students compared to fellow students from other subject groups at RWTH Aachen University.
- Regarding the types of exchange engineering students of RWTH tend to prefer studies rather than internships abroad which may be attributed to an extended network of partnering higher education institutions rather than industry partnerships abroad. Most students go abroad for 4–6 months which corresponds to one study term and obviously fits best into study curricula.
- There are only a few slight differences in the preferred countries of destination. While engineering students tend to prefer the US more than the European countries, their fellow students from other disciplines rather prefer to stay within European borders to gather international experiences. The foreign language nevertheless plays an important role in the decision for the country of destination in so far as the majority of students communicate in the respective language of the country.
- Most of the students who are currently abroad or who have already finished an international exchange report having gathered rather positive experiences. They rated the improvement of their language skills and the introduction to another culture as most relevant.
- Most problems among those with international experiences occurred with financing the exchange and with finding an appropriate accommodation abroad.

Especially engineering students face problems with communicating in the foreign language and with contacting local students.

- Regardless of the different planning and realization stages of an international exchange, students are mostly motivated by the prospect of improving their language skills, by getting to know a new culture, by enhancing their career options, by building new friendships, and by increasing their autonomy. The development of discipline-specific knowledge or other factors such as recommendations by counselors or getting to know another higher education systems seem to be less central.
- The major obstacles students face in any planning or realization phase are financial problems, time pressure during their studies, and too few exchange possibilities especially.
- For financing their stay abroad most students rely on private savings, their family's support, or scholarships – while the latter is especially important for engineering students. The minority of students finances international exchange through state-funded grants.
- The majority of survey participants report no problems in the recognition process of study credits. Nevertheless, those problems reported such as the long duration of the recognition process and problems with differing syllabi were most severely encountered among engineering students.

Those key findings suggest the following conclusions and requirements for further research.

There are several deviations in the results of the survey compared to prior studies such as the fact that engineering students at RWTH are not less mobile than other students or face fewer problems in the recognition process of study credits. This might be partly due to the specific situation at RWTH and its specialized programs for engineering students that already tackle those challenges successfully. Nevertheless, further investigations on the specific reasons and comparisons to other universities will become necessary. An in depth-analysis will have to measure what components of those programs and to what extent they successfully encourage outbound mobility among engineering students in order to facilitate their transfer to other higher education institutions.

It is striking that students can only integrate an international exchange when it is financed by their families due to lacking financial support by official bodies. This bears the danger of privileging one specific group of students and discriminating mainly students from lower social classes. As Finger [22] argues the social background of students is especially important when it comes to the decision to go abroad. Once students decided to go abroad the influence of the social background on the choice of country of destination and the duration of mobile periods decreases. Thus, in order to support wide ranging exchange programs more opportunities and financing options shall be offered. Further investigation on the social background especially of engineering students shall be undertaken in order to analyze the special needs of this group of students.

The survey has also shown that students seem to be mainly motivated to go abroad by improving their social competences and language skills. Thus, information and counseling should focus on those issues but should also point out the positive effects on an international exchange on the development of discipline-specific skills and the professional career.

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# Motivationen und Hindernisse für die Auslandsmobilität von Studierenden in MINT-Fächern – eine vergleichende Studie an der RWTH Aachen University

**Ute Heinze, Ursula Bach, René Vossen und Sabina Jeschke**

**Zusammenfassung** 64 von 1000 deutschen Studierenden absolvierten im Jahr 2010, laut DAAD, einen studienbezogenen Auslandsaufenthalt. Die Mobilitätsrate der verschiedenen Fachdisziplinen variiert jedoch stark. Besonders unter den Studierenden der Ingenieurwissenschaften ist die Mobilitätsrate mit 4 % vergleichsweise gering. Während aktuelle Statistiken lediglich den Ist-Zustand abbilden, gibt es wenige Daten zu den Gründen hinter der bei Ingenieuren geringer ausfallenden Auslandsmobilität.

Daher wurde vom IMA/ZLW & IfU in enger Kooperation mit dem International Office der RWTH im November 2012 eine weitreichende Online Umfrage unter sämtlichen Studierenden der Universität durchgeführt. Die Studie "GoING abroad – Auslandsmobilität an der RWTH Aachen University" konzentrierte sich auf mobilitätsfördernde sowie -hemmende Faktoren. Dabei konnte einerseits festgestellt werden, dass die Ingenieurstudierenden an der RWTH vergleichsweise häufig ins Ausland gehen. Motivationsgründe sind hauptsächlich die Verbesserung von Fremdsprachenkenntnissen oder das Kennenlernen einer neuen Kultur. Hindernisse werden vor allem bei der Anerkennung der im Ausland erbrachten Studienleistungen berichtet.

**Schlüsselwörter** Auslandsmobilität · Deutsche Studierende im Ausland · MINT-Wissenschaften · Interkulturelle Kompetenzen · Internationalisierung

## 1 Einleitung

Durch die Globalisierung müssen Unternehmen vermehrt international denken und handeln. Interkulturelle Erfahrungen und Kompetenzen prägen zunehmend auch das Berufsfeld und -profil von Wissenschaftlerinnen und Wissenschaftlern der Natur- und Ingenieurwissenschaften sowie der Informatik. Diesen globalen Entwicklungen

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und Herausforderungen müssen auch Hochschulen durch eine adäquate Ausbildung begegnen. Aus diesen Gründen ist es wichtig, dass sich Studierende während des Studiums die Fähigkeit aneignen, mit Menschen aus anderen Kulturen zusammenzuarbeiten um diese Qualifikation später sicher auf dem globalen Arbeitsmarkt anzuwenden zu können [1].

Aktuelle Statistiken, auf die im Folgenden noch detaillierter eingegangen wird, zeigen, dass Studierende der mathematisch-naturwissenschaftlichen, informatischen und vor allem technisch-ingenieurwissenschaftlichen Fächer (kurz MINT-Fächer) weitaus weniger auslandsmobil sind als Studierende bspw. aus den Rechts-, Wirtschafts- oder Sozialwissenschaften [2–5]. Über die Gründe ist laut Heublein et al. [6] bisher wenig bekannt, so dass lediglich hypothetische Annahmen dazu getroffen werden können. Es wird vermutet, dass die Umstellung der Studiengänge auf das Bachelor-/Mastersystem und die damit einhergehende Zeitproblematik, einen Auslandsaufenthalt in das Studium zu integrieren, einen nicht unwesentlichen Einfluss auf die Auslandsmobilität ausüben [7].

Um jedoch die Beweggründe der Studierenden insbesondere aus MINT-Fächern für oder gegen studienrelevante Auslandsaufenthalte näher zu beleuchten, wurde im Rahmen des Projekts Exzellentes Lehren und Lernen in den Ingenieurwissenschaften (ELLI) im November 2012 eine Studierendenbefragung an der Rheinisch-Westfälischen Technischen Hochschule (RWTH) Aachen University unter der Leitung des Lehrstuhls für Informatik im Maschinenbau (IMA), des Zentrums für Lern- und Wissensmanagement (ZLW) und des Instituts für Unternehmenskybernetik (IfU) in Kooperation mit dem International Office der RWTH durchgeführt. Die Intention der Studie war die Ermittlung der Motivationen und Hindernisse für Auslandsmobilität insbesondere der Studierenden der MINT-Fächer an der RWTH Aachen University. Berücksichtigt wurden finanzielle Belange, Anerkennungsprozesse, universitäre Informations- und Beratungsangebote sowie persönliche Gründe für die Entscheidung für oder gegen einen studienbezogenen Auslandsaufenthalt.

Nach einer kurzen Beschreibung vorangehender Studien zur Auslandsmobilität deutscher Studierender in MINT-Fächern wird zunächst auf die angewandte Methodik der RWTH-internen Studie näher eingegangen, bevor die erzielten Ergebnisse dargestellt werden.

## 2 Studien zur Auslandsmobilität von Studierenden der MINT-Fächer

Laut der Datengrundlage des Deutschen Akademischen Austauschdienstes (DAAD) und des Instituts für Hochschulforschung (HIS) [2] sowie des Statistischen Bundesamtes [3] absolvierten 2010 insgesamt 64 von 1000 an deutschen Hochschulen eingeschriebenen Studierenden einen studienrelevanten Auslandsaufenthalt. Diese Zahl beinhaltet sowohl zeitweilig an einer ausländischen Hochschule immatrikulierte Studierende, als auch jene, die einen Studienabschluss im Ausland anstrebten.

Zahlen zu den Mobilitätsraten der verschiedenen Fachdisziplinen sind bisher hauptsächlich nur für das europäische Austauschprogramm ERASMUS erfasst worden. Demnach verweilen im Studienjahr 2010/2011 von insgesamt 30.274 deutschen ERASMUS-Austauschstudierenden ca. 40 % (12.174) von ihnen aus den Rechts-, Wirtschafts- und Sozialwissenschaften im Ausland, gefolgt von ca. 25 % (7.531) aus den Geisteswissenschaften und der Kunst, ca. 12 % (3.726) aus den Ingenieurwissenschaften sowie ca. 9 % (2.956) aus naturwissenschaftlichen, mathematischen und informatischen Studienfächern [2]. Auch andere Studien wie bspw. die 19. Sozialerhebung des Deutschen Studentenwerks [4] kommen zu einem ähnlichen Ergebnis und bestätigen eine Tendenz zu geringer Auslandsmobilität unter Studierenden der MINT-Fächer.

Einige wenige Studien untersuchen die Motivation und Hindernisse von Studierenden bei der Planung und Durchführung eines Auslandsaufenthaltes. Laut Analysen des DAAD [5], der HIS [8] oder des nordrhein-westfälischen Ministeriums für Innovation, Wissenschaft und Forschung [9] werden die folgenden Hindernisse häufig von Studierenden angeführt:

- Probleme bei der Anerkennung von Studienleistungen,
- Zeitverlust im Studium,
- Probleme bei der Vereinbarkeit des Auslandsaufenthaltes mit den an der Heimathochschule geforderten Leistungen sowie
- finanzielle Probleme.

Wie bereits Heublein et al. [6] feststellen, sind weitergehende Studien zur Motivation der Studierenden bei der Planung und Umsetzung von Auslandsaufenthalten rar. Deshalb zielt die im Folgenden beschriebene Studie darauf ab, motivierende und hemmende Faktoren für die Durchführung eines studienrelevanten Auslandsaufenthaltes von Studierenden an der RWTH Aachen University im Vergleich zwischen MINT-Studierenden und Nicht-MINT Studierenden näher zu beleuchten.

## 3 Methodik

### *3.1 Online-Fragebogen*

Die Befragung „Going abroad - Auslandsmobilität an der RWTH Aachen University“ richtete sich an alle Studierenden mit deutscher oder ausländischer Staatsangehörigkeit, die ihre Hochschulzugangsberechtigung an einer deutschen Ausbildungseinrichtung erworben haben, sogenannte „Bildungsinländer“. Insgesamt wurden $n = 33.003$ Studierende gebeten, an der Studie teilzunehmen. Mit $N = 3.218$ vollständig auswertbaren Fragebögen beträgt die Rücklaufquote 9,75 %.

Um möglichst viele Studierende zu erreichen, wurde die Studie als Online-Umfrage implementiert und über die Zeitspanne von vier Wochen vom 5. - 30. November 2012 mithilfe einer E-Mail-Benachrichtigung sowie einer Erinnerung nach zwei Wochen verbreitet. Die Stichprobe wurde zudem durch Filterfragen in verschiedene Gruppen mit entsprechend individuell zugeschnittenen Fragen eingeteilt, um so möglichst präzise auf verschiedene Planungs- und Durchführungsphasen eines Auslandsaufenthaltes eingehen zu können.

## *3.2 Stichprobenbeschreibung*

### 3.2.1 Demografische Daten

Die erhobene Stichprobe zeigt auf, dass mit 61,5 % der Großteil der befragten Studierenden männlich ist. 3.064 Teilnehmende stammen aus Deutschland (ca. 95 %), 16 aus China (ca. 0,5 %), 15 aus der Türkei (ca. 0,5 %) und 10 aus Russland (0,3 %). Die Hochschulzugangsberechtigung erlangten 97,4 % der Befragten in Deutschland.

### 3.2.2 Studienbezogene Daten

Im Vergleich zu der Verteilung der Gesamtanzahl der an der RWTH eingeschriebenen Studierenden im Wintersemester 2012/2013 [10] verteilten sich die Teilnehmenden der Studie in einem ähnlichen Verhältnis auf die jeweiligen Fakultäten wie die folgende Abb. 1 zeigt. Somit kann keine Verschiebung innerhalb der Daten zugunsten einer bestimmten Fakultät beobachtet werden, weswegen die Ergebnisse der Studie einen repräsentativen Schnitt der Studierenden abbilden.

Die Befragungsteilnehmenden strebten unterschiedliche akademische Grade an. Die drei am häufigsten vertretenen Gruppen in Bezug auf den angestrebten akademischen Abschluss waren Masterstudierende mit 44,3 %, Bachelorstudierende mit 26,5 % und Promovenden mit 11,7 %.

# 4 Ergebnisse der Studie

Um die Beweggründe bei der Planung und Organisation eines Auslandsaufenthaltes von Studierenden der MINT-Fächer im Vergleich zu Studierenden der Nicht-MINT Fächer zu analysieren, wird sich die weitere Auswertung der Ergebnisse auf die Motivationen und Hindernisse bei der Organisation eines Auslandsaufenthaltes der Studierenden der Fakultäten Mathematik, Informatik, Naturwissenschaften, Bauingenieurwesen, Maschinenwesen, Georessourcen und Materialtechnik sowie Elektrotechnik und Informationstechnik konzentrieren und sie gegen jene der Studierenden der Fakultäten für Architektur, Philosophie, Wirtschaftswissenschaften und Medizin abgrenzen. Insgesamt nahmen $N = 2.507$ Studierende der MINT-Fächer an der Umfrage teil, was einem Anteil von 12,3 % der Gesamtstudierenden der MINT-Fächer der RWTH Aachen University entspricht.

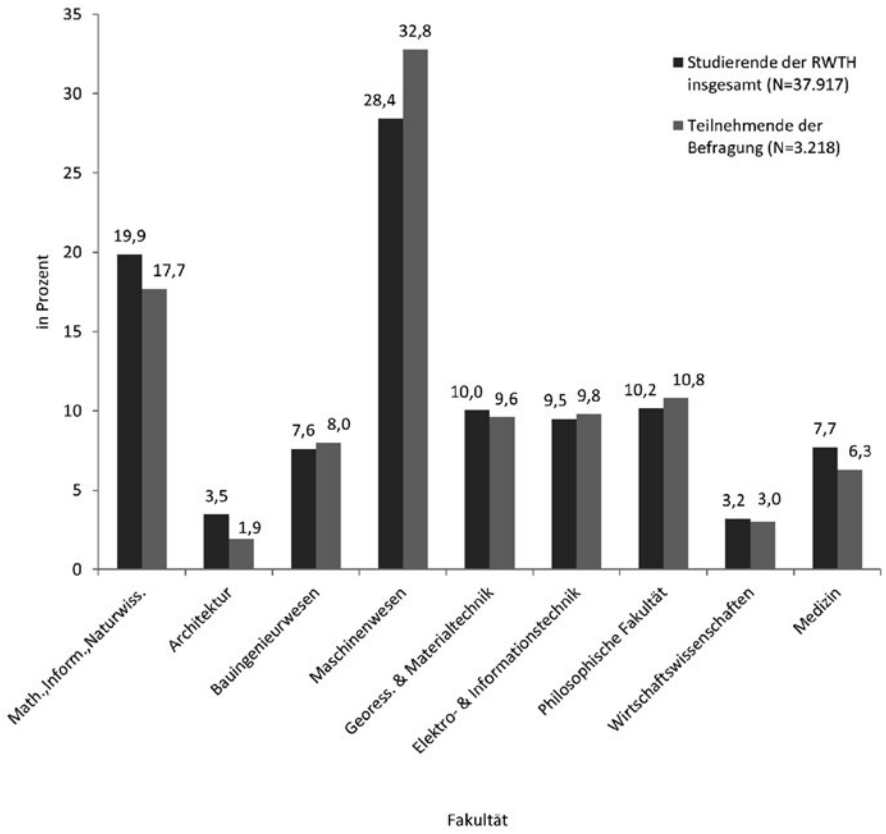


**Abb. 1** Verteilung der Befragten über die Fakultäten

## *4.1 Mobilitätsverhalten der Studierenden in MINT-Fächern*

### 4.1.1 Stadium des Auslandsaufenthaltes

Die Teilnehmenden der Studie befanden sich in unterschiedlichen Planungs- und Durchführungsphasen ihres Auslandsaufenthaltes bzw. hatten überhaupt keinen Auslandsaufenthalt vorgesehen, wie Abb. 2 zeigt.

Demnach waren insgesamt 34,9 % der befragten MINT-Studierenden zum Zeitpunkt der Umfrage im Ausland bzw. hatten bereits Auslandserfahrungen im Studium gesammelt. 32,9 % planen einen Auslandsaufenthalt und insgesamt 32,3 % planen keinen Auslandsaufenthalt ein bzw. traten einen zuvor geplanten Auslandsaufenthalt nicht an. Somit ergibt sich hier fast eine Gleichverteilung auf die unterschiedlichen Planungs- und Durchführungsstadien.

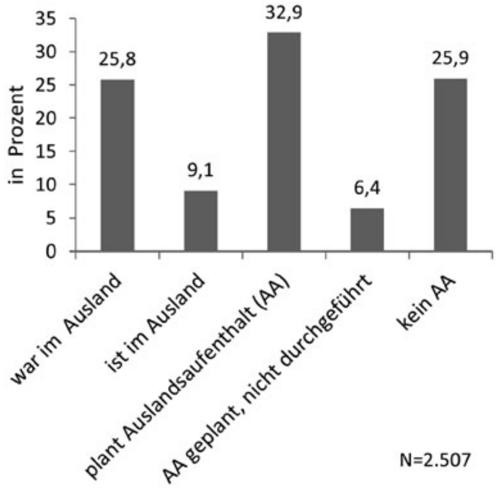


**Abb. 2** Planungs- und Durchfü]hrungsphasen des Auslandsaufenthaltes der Befragten

**Tab. 1** Kontigenztabelle für das Mobilitätsverhalten von MINT- und nicht-MINT-Studierenden

| | war/ist im Ausland | war (bisher) nicht im Ausland | Gesamt |
|---|---|---|---|
| MINT-Studierender | 873 | 1634 | 2507 |
| kein MINT-Studierender | 234 | 477 | 711 |
| Gesamt | 1107 | 2111 | 3218 |

### 4.1.2 Mobilität der MINT-Studierenden im Vergleich

Vergleicht man die Mobilitätsrate der Studierenden der MINT-Fächer mit Studierenden der anderen Fakultäten der RWTH Aachen University, bringt die Studie keine spezifischen Erkenntnisse hervor. Die Mobilität der Befragten der Fakultäten Mathematik, Informatik und Naturwissenschaften, Bauingenieurwesen, Maschinenwesen, Georessourcen und Materialtechnik sowie Elektrotechnik und Informationstechnik („MINT-Studierender") wurden mit jener der Studierenden der Fakultät für Architektur, der Philosophischen, Wirtschaftswissenschaftlichen und Medizinischen Fakultäten („kein MINT-Studierender") verglichen. Dabei bemaß sich die Mobilität danach, ob die Teilnehmenden während ihres Studiums bereits einen Auslandsaufenthalt absolviert hatten oder sich während der Umfrage im Ausland befanden. Diese Befragten wurden der Variable „war/ist im Ausland", alle anderen der Variable „war (bisher) nicht im Ausland" zugeordnet. Die folgende Tab. 1 verdeutlicht die Häufigkeitsverteilung der getesteten Variablen.

Der Chi-Quadrat-Test nach Pearson wurde auf die zwei nominal skalierten Variablen „MINT-Studierender" und „kein MINT-Studierender" sowie „war (bisher) nicht im Ausland" und „war/ist im Ausland" durchgeführt. Folgende Werte wurden berechnet:

$$\chi^2(1, N = 3218) = .90; p = .05 \rightarrow \text{nicht signifikant}$$

Die Ergebnisse können die Nullhypothese nicht bestätigen. Es kann keine signifikante Aussage über die Mobilitätsaffinität hinsichtlich verschiedener Fakultäten getroffen werden. Es kann also durch die vorliegende Untersuchung nicht festgestellt werden, dass Studierende der MINT-Fächer weniger mobil als Studierende anderer Fakultäten sind. Somit kann kein Zusammenhang zwischen der Zugehörigkeit zu den MINT-Fakultäten und einem Auslandsaufenthalt identifiziert werden.

Dies steht im deutlichen Gegensatz zu den Zahlen bisheriger Studien (siehe Kap. 1), die über eine gravierend geringere Mobilität der Studierenden in MINT-Fächern berichten. Über Gründe hierfür kann allerdings nur gemutmaßt werden, da diese Befragung darüber keinen Aufschluss gibt. Es ist zu vermuten, dass sich einerseits die Effekte der besonderen Förderung der Auslandsmobilität von MINT-Studierenden an der RWTH zeigen. Vor allem ein breit gestreutes Informationsnetzwerk an Auslandsstudienbeauftragten an den Fakultäten hilft dabei, Studierende aktiv bei der Planung und Durchführung ihres Auslandsaufenthaltes zu unterstützen. Andererseits ist jedoch auch ein Selektionseffekt durch eine nicht konsistente Randomisierung der Stichprobe nicht auszuschließen. Eventuell nahmen eher mobilitätsaffine Studierende an der Befragung teil und beeinflussten die Ergebnisse entsprechend.

## *4.2 Motivation für studienrelevante Auslandsaufenthalte*

Die Studienteilnehmenden wurden dazu aufgefordert, einer Reihe von möglichen Motivationsgründen auf einer 6-stufigen Skala einen Wert von 1 (gar kein Motivationsgrund) bis 6 (großer Motivationsgrund) zuzuordnen. Anschließend wurden die Mittelwerte der Bewertungen errechnet, um somit eine Aussage über die Motivation für studienrelevante Auslandsaufenthalte treffen zu können. Die folgende Abb. 3 zeigt einerseits die abgefragten Kriterien und andererseits die jeweils

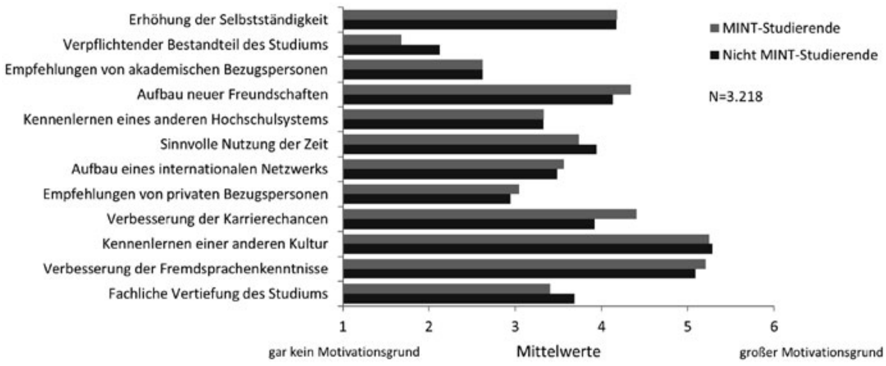


**Abb. 3** Motivation für studienrelevante Auslandsaufenthalte für MINT- und Nicht MINT-Studierende

dazugehörigen Bewertungen der MINT-Studierenden sowie der Studierenden der anderen Fakultäten („Nicht MINT-Studierende").

Disziplinübergreifend wurden solche Faktoren wie die Verbesserung der Fremdsprachenkenntnisse, das Kennenlernen einer neuen Kultur, der Aufbau neuer Freundschaften sowie die Erhöhung der Selbstständigkeit als besonders große Motivationsgründe bewertet. Diese hauptsächlich der Gruppe der Soft Skills zuzuordnenden Faktoren wirken offenbar stärker auf die Motivation als andere Faktoren wie bspw. die fachliche Vertiefung des Studiums oder das Kennenlernen eines anderen Hochschulsystems. Die Bedeutung der Empfehlungen von privaten oder akademischen Bezugspersonen wurde disziplinübergreifend als gering eingeschätzt. Am wenigsten wurde eine Verpflichtung zu einem Auslandsaufenthalt als Motivationsgrund angegeben, was jedoch darauf zurückzuführen ist, dass in den wenigsten Curricula bisher Auslandsaufenthalte als verpflichtende Bestandteile vorgesehen sind.

Unterschiede zwischen den Fachdisziplinen wurden in Bezug auf die Wertung folgender motivierender Faktoren festgestellt: sinnvolle Nutzung der Zeit, fachliche Vertiefung des Studiums und die Verbesserung der Karrierechancen. Der Aspekt der sinnvollen Nutzung ihrer Zeit bei einem Auslandsaufenthalt wird von Studierenden der MINT-Fächer im Vergleich zu anderen Studierenden als geringerer Motivationsgrund eingeschätzt. Eine ähnliche Wertung wurde auch für die fachliche Vertiefung des Studiums gegeben. Erstellt man eine Rangliste der zwölf oben dargestellten Motivationsgründe und sortiert sie aufsteigend nach ihrer Bewertung, so befindet sich das Kriterium „fachliche Vertiefung des Studiums" auf Rang 8 bei MINT und auf Rang 7 bei nicht MINT-Studierenden. Somit zeigt sich, dass dieses Kriterium für Studierende aller Fachrichtungen gleichermaßen weniger als Motivationsgrund für die Durchführung eines Auslandsaufenthaltes dient. Die Verbesserung der Karrierechancen hingegen motiviert Studierende der MINT-Fächer wesentlich stärker dazu, ins Ausland zu gehen, als andere Studierende. Bei MINT-Studierenden werden verbesserte Karrierechancen als dritthäufigstes Kriterium genannt, während es bei nicht MINT-Studierenden nur auf Rang 6 liegt.

## *4.3 Hindernisse für studienrelevante Auslandsaufenthalte*

Bei der Betrachtung der Hindernisse zeigt sich ein ähnlich homogenes Bild, wie in der folgenden Abb. 4 dargestellt. Auch hier wurden die Befragten gebeten, ihre Bewertung der aufgeführten Hindernisse auf einer 6-stufigen Skala von 1 (gar kein Hindernis) bis 6 (großes Hindernis) abzugeben.

Als die wichtigsten Hindernisse für Auslandsaufenthalte während des Studiums werden vor allem Zeitdruck während des Studiums, finanzielle Gründe und zu wenig Austauschplätze genannt. Ebenso werden unklare Zuständigkeiten bei den für die Organisation eines Austausches relevanten Stellen von allen Studierenden gleichermaßen als hemmend eingestuft. Am wenigsten fühlen sich Studierende durch

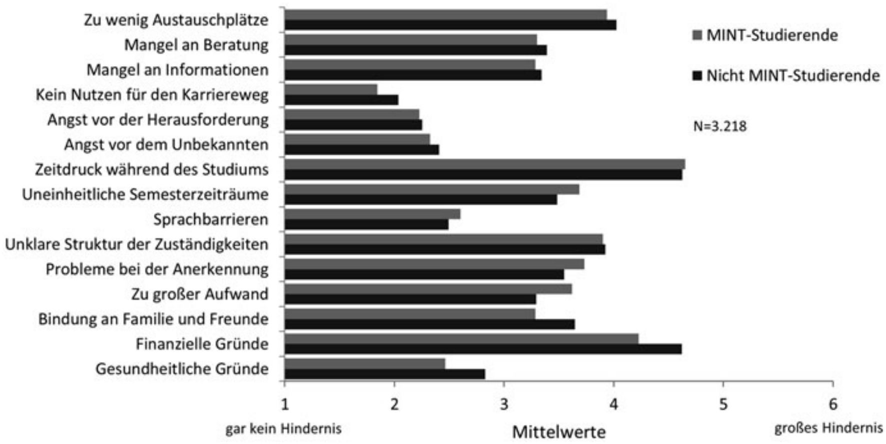


**Abb. 4** Vergleich der Hindernisse für Auslandsaufenthalte zwischen MINT- und Nicht MINT-Studierenden

einen nicht erkennbaren Nutzen für ihren Karriereweg, die Angst vor der Herausforderung oder dem Unbekannten sowie Sprachbarrieren an der Durchführung eines Auslandsaufenthaltes gehindert.

Unterschiede in den Bewertungen zwischen den Disziplinen sind bei den Hindernissen hingegen deutlich erkennbar. Vor allem Probleme bei der Anerkennung und ein mit dem Auslandsaufenthalt einhergehender zu großer zeitlicher Aufwand werden von Studierenden der MINT-Fächer vermehrt als Hindernis angegeben. Auch uneinheitliche Semesterzeiträume werden von MINT-Studierenden als hinderlicher bewertet als von anderen Studierenden. Als wesentlich weniger hinderlich schätzen Studierende der MINT-Fächer im Vergleich zu ihren Kommilitoninnen und Kommilitonen anderer Studienrichtungen gesundheitliche sowie finanzielle Gründe oder die Bindung an Freunde und Familie ein.

Damit werden die zuvor von anderen Studien ermittelten Ergebnisse (siehe Kap. 1 *Studien zur Auslandsmobilität von Studierenden der MINT-Fächer*) auch durch diese Studie bestätigt.

## 5 Zusammenfassung

Die vorgestellte Studie untersuchte motivierende und hemmende Faktoren, die Studierende der MINT-Fächer im Vergleich zu den Studierenden der Nicht-MINT-Fächer dazu veranlassen, einen Auslandsaufenthalt in ihr Studium zu integrieren oder nicht. Vergleicht man dabei die Top 5 der Motivationen und Hindernisse für MINT-Studierende ergibt sich folgende Tab. 2:

Neben den in der Praxis stark nachgefragten Soft Skills wie der Beherrschung von Fremdsprachen oder einer eigenständigen Arbeitsweise wird der Verbesserung

**Tab. 2** Top 5 der Motivationen und Hindernisse bei Auslandsaufenthalten unter MINT-Studierenden an der RWTH Aachen University

| Top 5 Motivationen | | Top 5 Hindernisse | |
|---|---|---|---|
| 1. | Kennenlernen einer anderen Kultur | 1. | Zeitdruck während des Studiums |
| 2. | Verbesserung der Fremdsprachenkenntnisse | 2. | Finanzielle Gründe |
| 3. | Verbesserung der Karrierechancen | 3. | Zu wenig Austauschplätze |
| 4. | Aufbau neuer Freundschaften | 4. | Unklare Struktur der Zuständigkeiten |
| 5. | Erhöhung der Selbstständigkeit | 5. | Probleme bei der Anerkennung |

der Karrierechancen eine höhere Priorität zugeordnet als bspw. der fachlichen Vertiefung des Studiums, die erst auf Platz 8 der Motivationsgründe rangiert (siehe auch Kap. 3.2). Diese Priorisierung scheint eine Tendenz zur Karriereorientierung der MINT-Studierenden anzudeuten: Für den Fall, dass Studierende der MINT-Fächer eine Verbesserung ihrer Karrierechancen durch einen Auslandsaufenthalt als gering einschätzen und sich zusätzlich bestimmter Hindernisse wie hohem Zeitdruck oder fehlender finanzieller Unterstützung ausgesetzt sehen, werden sie vermutlich keinen Auslandsaufenthalt organisieren. Hinzu kommt die besondere soziale Situation der Studierenden der MINT-Fächer. Wie die 18. Sozialerhebung des Deutschen Studentenwerks [11] zeigt, immatrikulieren sich häufig Studierende der „unteren sozialen Herkunftsgruppen" in Bezug auf allgemein und berufsbildende Abschlüsse und die berufliche Stellung der Eltern für ein Studium der Ingenieurwissenschaften - einem der großen MINT-Fächer. Somit liegt die Vermutung nahe, dass mit der sozialen Herkunft auch eine entsprechende finanzielle Unterstützung der Studierenden durch das Elternhaus einhergeht. Finanzielle Probleme wiederum zählen zu den Haupthindernissen bei der Organisation eines Auslandsaufenthaltes.

Wie auch schon von Heublein et al. [6] angemerkt, scheint sich die Entwicklung der Auslandsmobilität derzeit in einer Übergangsphase zu befinden. Trotz vermehrter Förderbemühungen stagnierten die Mobilitätsraten zwischen 2000 und 2010. Die Bedeutung eines Auslandsaufenthaltes für die zukünftige Berufstätigkeit wird jedoch von Studierenden durchweg als hoch eingeschätzt. Dies wird nicht zuletzt durch eine erhöhte Nachfrage an Absolventen mit fremdsprachlichen Kompetenzen von global agierenden Unternehmen gefördert. Diese begünstigenden Faktoren lassen darauf hoffen, dass sich die Rate an auslandsmobilen Studierenden in den kommenden Jahren weiter steigern wird.

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# Was macht den Traumjob Wissenschaft aus? Ergebnisse des World Cafés auf der 6. GEW-Wissenschaftskonferenz 2012 in Herrsching

**Ute Heinze, Claudia Jooß, Esther Borowski, Doreen Pöschl, Anna Schütz, René Vossen und Sabina Jeschke**

**Zusammenfassung** Angeleitet durch die Methode des World Cafés fand im Kontext der 6. GEW-Wissenschaftskonferenz 2012 in Herrsching ein Austausch zur Thematik „Was macht den Traumjob Wissenschaft aus?\" statt. Auf Basis der Erfahrungen der heterogen durchmischten Teilnehmergruppe von Studierenden, WissenschaftlerInnen und weiteren Experten, wurden 5 Schwerpunktthemen identifiziert und diskutiert: Arbeitsgestaltung, Hochschulstrukturen, wissenschaftliche Qualifizierung und Personalentwicklung, Wünsche und Utopien. Neben der Darstellung der wichtigsten Inhalte der einzelnen Schwerpunkte schließt der Beitrag mit einem Fazit zur eingangs gestellten Frage ab und zeigt zusammenfassend die Aspekte auf, welche die Attraktivität einer wissenschaftlichen Karriere ausmachen.

**Schlüsselwörter** Wissenschaftskarriere · Hochschulforschung · Großgruppenmethoden · Personalentwicklung

## 1 Einleitung

Wenn an einem Ort Studierende, Wissenschaftlerinnen und Wissenschaftler sowie weitere Expertinnen und Experten des Arbeitsfelds Wissenschaft und Hochschule mit dem Ziel zusammenkommen, sich über Karrierewege und Beschäftigungsbedingungen an Hochschulen auszutauschen, ist zum einen davon auszugehen, dass jede Menge Erfahrungen und Sichtweisen aufeinander treffen. Diese ähnlichen aber auch unterschiedlichen Erfahrungen lösen zum anderen kontroverse und zugleich interessante Diskussionen aus. Im Rahmen von Konferenzen – wie der GEW-Wissenschaftskonferenz –, die im Angesicht der Perspektivenvielfalt ihrer

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Themen ein dichtes Programm aufbieten, werden diese Diskussionen allzu oft in kleinen Runden jenseits der Hauptbühne geführt. Ihnen wird nur selten ein eigener Platz im Kongressprogramm eingeräumt. Daher wurde in Herrsching in Bayern die Möglichkeit geboten, in einem World Café gezielt mit den Kolleginnen und Kollegen aus unterschiedlichen Kontexten in einen Austausch zu treten, was denn den Traumjob Wissenschaft eigentlich ausmacht. In wechselnden Cafèrunden entstanden auf der Basis der individuellen, spezifischen Erfahrungen der Beteiligten kritische Diagnosen des Ist-Zustands, Utopien einer neuformierten Hochschule sowie diskursive Analysen hinsichtlich der Stolpersteine und Gelingensbedingungen attraktiver Karrierewege und Beschäftigungsbedingungen im Wissenschaftssystem. Der folgende Artikel gibt zunächst eine kurze Einleitung zur Methode des World Cafés bevor er die erarbeiteten Ergebnisse zusammenfasst.

## 2 Dialogmethode World Café

Bei dieser Dialogmethode geht es darum, möglichst viele Beteiligte (für 20 bis zu über 100 Personen geeignet) zu einem bestimmten Thema oder einer Fragestellung – hier „Was macht den Traumjob Wissenschaft aus?\ – zu Wort kommen zu lassen. Wie die Bezeichnung World Café, in Anlehnung an ein Kaffeehaus, bereits vermuten lässt, ist eine entspannte Atmosphäre von zentraler Bedeutung. Die Kombination aus offener, kommunikationsfördernder Atmosphäre und der Ausrichtung auf Partizipation aller Beteiligten im Kontext einer nicht hierarchischen Organisation zielt darauf ab, die intrinsische Motivation zu steigern, kollektives Wissen nutzbar zu machen und einen Informationstransfer zwischen sonst häufig isolierten Bereichen zu ermöglichen [1]. Da die Zielsetzungen nicht starr und Ergebnisse nicht antizipierbar sind, können innovative Querdenker zu Wort und unerwartete Ergebnisse zustande kommen. Insgesamt wird ein kreativer Umgang mit Fragestellungen und Problemen ermöglicht [1]. Die Methode ist besonders wirkungsvoll bei heterogenen, durchmischten Teilnehmergruppen, die ein gemeinsames Thema bearbeiten [2].

Die Teilnehmenden sammeln und diskutieren ihre Ideen, Meinungen, Erfahrungen und ihr Wissen zum Thema und visualisieren diese auf den mit beschreibbarem Papier bedeckten Tischen. Rundenweise wechseln die Teilnehmenden die Tische und diskutieren in einer neuen Konstellation dieselbe oder eine andere Thematik. Durch die Mehrfachbearbeitung desselben Themas sowie durch die unterschiedlichen Gruppen, werden innovative Ideen gleichermaßen gefördert und hinterfragt sowie eine breite Streuung der Information erreicht. Moderatorinnen und Moderatoren als Gastgebende unterstützen die Runden, indem sie in die Fragestellung einführen, das vorangegangene Gespräch zusammenfassen, strukturieren oder den Diskurs neu in Gang bringen [1].

Mit diesem Artikel wird der Versuch unternommen, die Ergebnisse des Herrschinger World Cafés festzuhalten, nicht zuletzt, um das Engagement der

Beteiligten über das World Café hinaus fruchtbar zu machen und der Gefahr der Flüchtigkeit solcher Diskussionen entgegenzuwirken. Dafür haben die Autorinnen und Autoren die entstandenen Tischplakate ausgewertet und geclustert, wodurch mit den Themen Arbeitsgestaltung, Hochschulstrukturen, wissenschaftliche Qualifizierung und Personalentwicklung, Wünsche und Utopien fünf Themenstränge entstanden sind, auf die im Folgenden eingegangen werden soll. Dabei ist darauf hinzuweisen, dass ex post lediglich die visualisierten Ergebnisse und keine Sprachaufnahmen o. ä. zur Auswertung zur Verfügung stehen und die Ideen und Ergebnisse eines World Cafés an eine Veranstaltung gebunden sind [1].

## 3 Arbeitsgestaltung

Als ein Kernthema wurde in den Diskussionen der Aspekt der Zeit problematisiert, so doch gute wissenschaftliche Arbeit, verstanden als „das Bohren dicker Bretter\, ebenso Zeit und Muße wie dauerhafte kontinuierliche Beschäftigung bedarf. Auch die Verwirklichung einer angemessenen *Work-Life-Balance* ist nur mit ausreichenden zeitlichen Ressourcen denkbar, wobei die Zeit wissenschaftlicher Tätigkeiten zum einen als finanzierte Zeit und zum anderen als Zeitraum für Ideen und kreative Entfaltung gedacht werden muss. Produktionsdruck und Arbeitsverdichtung durch Arbeitgeber und die steigenden Ansprüche des Wissenschaftssystems, so ein breiter Konsens der gemeinsamen Debatte, beschädigen die Qualität von Wissenschaft mehr, als dass sie als Garanten von Innovation gesehen werden können.

## 4 Hochschulstrukturen

Das grundlegende Problem, auf das in allen Gesprächen im- oder explizit verwiesen wurde, ist die *mangelhafte Grundfinanzierung* der Hochschulen, die sich einerseits, trotz des Anspruchs auf Wettbewerbsfähigkeit, auf die Hochschulangehörigen, ihre Besoldung sowie ihre Tätigkeit projiziert und häufig zu einer Verwaltung von Mangel führt. Andererseits steigt die *Abhängigkeit von Drittmitteln*, welches das Problem der Grundfinanzierung und des Wettbewerbs zum Beispiel aufgrund von leistungsorientierter Mittelvergabe verschärft. Hier wird ein Spannungsverhältnis zwischen konzentrierter und qualitativ hochwertiger Forschung auf der einen Seite und der Sicherung von Finanzierungen bzw. der Ausrichtung am Mainstream auf der anderen Seite ausgemacht. Ein weiteres Spannungsverhältnis zeigt die Diskussion zur Einrichtung der *Lehrprofessur*, die, entsprechend dem angelsächsischen Modell, eine Fokussierung auf die Lehre auf Kosten der Forschung bedeutet und damit dem Humboldt‘schen Ideal der Einheit von Forschung und Lehre entgegensteht.

## 5 Wissenschaftliche Qualifizierung und Personalentwicklung

Trotz vieler Kritik wird die wissenschaftliche Arbeit in den Diskussionen durchaus als *Traumjob* beschrieben, was insbesondere auf der Begeisterung und intrinsischen Motivation für die Tätigkeit beruht. Diese Begeisterung basiert zugleich auf spezifischen Rahmenbedingungen als auch auf der inhaltlichen Spezifik, zumal wissenschaftliche Arbeit als gesellschaftlich bedeutsam und facettenreich beschrieben wird. Die wissenschaftliche Arbeit, so die Teilnehmenden, sei abwechselnd, vielfältig, verändernd und an der Generierung neuer Erkenntnisse ausgerichtet und somit als lebenslanges Lernen hinsichtlich einer Lust des Dazulernens attraktiv. Damit geht einher, dass eine intrinsische Motivation zum Forschen gegeben sein und eine Würdigung der Forschungsergebnisse erfolgen muss. Auf der Haben-Seite stehen zudem die an individuellen Interessen ausgerichtete Arbeit und die Möglichkeit, sich in einem produktiven Umfeld und Netzwerk längere Zeit intensiv mit einer Sache beschäftigen zu können.

Weiterhin wurde der spannungsreiche Aspekt der *Wissenschaftsfreiheit und -unabhängigkeit* diskutiert. Dafür werden Freiräume für Ideen, wissenschaftliche Neugier, ergebnisoffene Forschung, wissenschaftlicher Austausch und individuelle Entwicklung als basal und zugleich als Verpflichtung der Wissenschaftlerinnen und Wissenschaftler angesehen. Eine förderliche Kultur in den Hochschulen und Forschungseinrichtungen ist dafür ebenso notwendig, wie entsprechende Rahmenbedingungen. Allerdings äußerten die Teilnehmerinnen und Teilnehmer des World Cafés auch die Befürchtung, dass vor allem die Autonomiebestrebungen der Hochschulen und Forschungseinrichtungen dazu führen könnten, entstehende Spielräume zu Ungunsten der Beschäftigten auszulegen. Zu den förderlichen Rahmenbedingungen zählen jedoch laut Meinung der Diskutierenden vor allem die soziale Absicherung und eine adäquate Tätigkeitsgestaltung der Arbeitnehmerinnen und -nehmer. Aufgabe der Gewerkschaften sei es in diesem Fall, die Arbeitnehmerinnen und -nehmer zu stärken und dabei zu unterstützen, für entsprechende Arbeitsverhältnisse einzustehen.

Im Bereich der Qualifizierungsphasen sticht vor allem der Aspekt der *wissenschaftlichen Betreuung und Begleitung* ins Auge. Diese solle einen verantwortungsvollen und verlässlichen Charakter haben, inhaltlich und methodisch Orientierung und Perspektive bieten sowie durch regelmäßige, faire (Personal-)Gespräche und Vereinbarungen Sicherheit bieten. Als besonders problematisch werden Abhängigkeitsverhältnisse zwischen Betreuenden und sich Qualifizierenden benannt. So sind die Betreuenden von Qualifizierungsarbeiten zumeist nicht nur begleitend und bewertend tätig sondern sind ebenso Arbeitgebende mit entsprechenden Anforderungen. Neutrale, externe Mentorinnen und Mentoren in allen Qualifizierungsphasen sind eine Idee der Teilnehmenden, diese Abhängigkeitsverhältnisse zu durchbrechen.

## 6 Wünsche

Die im Rahmen des World Cafés angeführten Wünsche repräsentieren die zuvor dargestellten Diskussionen zur Arbeit in der Wissenschaft. Der Austausch an den Tischen thematisierte strukturelle sowie kulturelle Rahmenbedingungen sowie die Aspekte Finanzierung, Wissenschaftsfreiheit und -unabhängigkeit sowie Qualifizierung. Diskutiert wurden die *unbefristete Beschäftigung* als Regel, berufliche *Sicherheit und Kontinuität* sowie *Alternativen zur Professur* auf gleichem Statuslevel. Eine besonders intensive Auseinandersetzung entstand bezüglich der *Wertschätzung der Lehre* mit dem Wunsch nach Anreizen für gute Lehre, Berücksichtigung von Lehrqualität in Berufungen sowie keiner zu starken Trennung von Forschung und Lehre. Hinsichtlich der *universitären Kultur* wurde mehr Transparenz, Ehrlichkeit sowie Kooperation und Solidarität statt Konkurrenzdenken gewünscht. Die Wünsche hinsichtlich der Finanzierung adressierten v. a. eine solide Ausfinanzierung aus dem Haushalt. Hinsichtlich der *Wissenschaftsfreiheit und -unabhängigkeit* wurde die Balance zwischen Innovation und Kontinuität, aber auch zwischen Entfaltung und Arbeitsorganisation als wünschenswert erachtet. Weitere Themen reichten von dem Wunsch nach intersektionaler Mobilität über die Partizipation an unterschiedlichen Forschungsereignissen bis hin zur Interdisziplinarität ohne Hürden und die Notwendigkeit von Basisqualifikationen zu Arbeitsrecht und Personalführung.

## 7 Utopien

Schlussendlich entwickelten die Teilnehmerinnen und Teilnehmer im Rahmen des World Cafés die Utopie der *Genossenschaftshochschule*, die einerseits die zuvor geäußerten Wünsche umsetzt aber auch Ansatzpunkte zur Vermeidung der beschriebenen Gefahren liefert. So würde sie sich, insofern sie umgesetzt wird, durch die folgenden Aspekte auszeichnen. Traditionelle Macht- und Abhängigkeitsverhältnisse zwischen wissenschaftlichem und administrativem Hochschulpersonal wären aufgebrochen, so dass ein herrschaftsfreier und basisdemokratischer Ideenwettbewerb stattfindet. Die Betreuung und Bewertung wissenschaftlicher Arbeiten wäre strikt vom sonst bestehenden Dienstverhältnis zwischen Betreuenden und Betreuten getrennt. Auch solch konkrete Umsetzungsformen wie ein Einheitslohn, eine auf 30 h begrenzte wöchentliche Höchstarbeitszeit, Vertrauensarbeitszeiten ohne festgelegte Arbeitszeiten oder ein obligatorisches Praxissemester für alle Hochschulangehörigen wären Bestandteil dieser Hochschule. Einige der im World Café vermeintlich als utopisch diskutierten Aspekte wie bspw. die Umsetzung einer kinder- und familienfreundlichen Hochschule, die Unterstützung bei der Dual Career-Planung, die Umsetzung von Diversity-Maßnahmen, fachliche Weiterbildungen oder die Anerkennung der Lehre haben bereits heute an einigen Hochschulen Einzug erhalten.

## 8 Ausblick

In den Diskussionen wurden verschiedene Wege des strukturellen Wandels aufgezeigt, die es nach dem Wunsch der Teilnehmenden als nächste Schritte auf dem Weg zum Traumjob Wissenschaft umzusetzen gilt. Zunächst wurde deutlich, dass nur mittels einer verlässlichen Drittmittelstruktur auch eine verlässliche Stellenstruktur geschaffen werden kann, wobei Daueraufgaben auch mit unbefristeten Beschäftigungsverhältnissen ausgestattet werden sollen. Soziale Absicherung und Planbarkeit einer wissenschaftlichen Karriere sind ebenso wichtige Aspekte wie weiterführende Verknüpfung von Forschung und Lehre. Nicht zuletzt soll durch eine offene Hochschul- und Wissenschaftskultur der gegenseitige Austausch, Kritik und der Wettbewerb aller Beteiligten auf Augenhöhe gefördert werden.

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# Deutschland 2035: Von „Made in Germany“ zu „Enabled by Germany“ – und wie aus Bildung ein Exportschlager wird

**Klaus Henning**

**Zusammenfassung** Wird Deutschland dem Wettbewerbsdruck der Globalisierung standhalten können und wenn ja wie können wir seine Stärken dazu nutzten und in welchen Bereichen müssen wir ganz besonders hinschauen um den Herausforderungen der Zukunft wie den Demografischen Wandel, die Urbanisierung, die Ressourcenknappheit und den Klimawandel erfolgreich entgegenzutreten? Deutschland ist für die kommende Jahre sehr gut aufgestellt. In diesem Beitrag werden Perspektiven vorgestellt, die auf einen systemorientierten Innovationsansatz beruhen, der soziale, organisatorische und technische Innovation integriert, um für uns auch in Zukunft ein weltweites Alleinstellungsmerkmal im internationalen Wettbewerb zu ermöglichen.

**Schlüsselwörter** Familienunternehmen · Innovationsfähigkeit · Generationengerechtigkeit · Potentialentfaltung · Duale Bildung · Homo Zappiens

## 1 Deutschlands Stärken kennen lernen, um sie nicht zu verlieren

Globale Megatrends prägen die Märkte des 21. Jahrhunderts: Demografischer Wandel, Urbanisierung, Ressourcenknappheit und Klimawandel. Die Antworten auf so komplexe Fragen liegen in Systemlösungen. Technologische Systemkompetenz ist also weiter gefragt, der systemorientierte Innovationswettbewerb gewinnt an Bedeutung. Nur ein Innovationsansatz, der technische, organisatorische und soziale Innovation integriert, kann uns in Zukunft einen Wettbewerbsvorsprung schaffen und damit unseren Wohlstand und unsere Lebensqualität erhalten. Ein solch exportorientiertes und funktionierendes Innovationssystem ist ein wichtiger Baustein, um Deutschland gegen wirtschaftliche Krisen stark zu machen.

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Aus der eigenen Perspektive betrachtet, erscheint uns Deutschen vieles in Deutschland und Europa problematisch. Von außen gesehen sieht Deutschland überraschend anders aus. Eine Befragung von 120 Experten aus Politik und Wirtschaft in 21 Ländern weltweit hat gezeigt, dass wir auch jenseits guter Produkte „Made in Germany" einen guten Ruf in der Welt haben und geachtet werden[1]. Die Wahrheit liegt wohl irgendwo in der Mitte. Tatsächlich sind wir uns unserer Fähigkeiten nicht immer bewusst. Wir haben z. B. eine Kompetenz, gute Systeme aufzubauen und beim Aufbau solcher zu beraten, egal ob es bildungsbezogene, soziale oder betriebliche Systeme sind. Die Marke „Enabled by Germany" ist jetzt schon auf dem Weg zu einem neuen Weltruf. Deutschland ist ein Land, das sich in die nationale und internationale Arbeitsteilung durch geschickte Kooperation einbringt, ohne alles selbst machen zu wollen[2].

**Der Ruf von Experten rund um den Globus ist eindeutig:**

> Denke ich an Deutschland, denke ich an Technologie, Wissenschaft, Industrie, Umwelt, soziale Marktwirtschaft. – Japan

> Heute sehe ich in Deutschland ein sympathisches, komplexes, vielfältiges und positives Land, das sehr effizient und organisiert ist.– Frankreich

> Wenn es Deutschland gelingt, das Thema Infrastrukturinvestitionen grundsätzlich mit dem Thema Green Economy zu verknüpfen, wird das für Deutschland ein sehr erfolgreiches Wirtschaftsmodell werden.– China

Deutschland hat in den vergangenen Jahren intensive Anstrengungen unternommen, um unseren Standort noch attraktiver zu machen. Dass unser Land die Turbulenzen der internationalen Märkte bisher so gut überstanden und sich aus der weltweiten Wirtschaftskrise im Jahr 2008 wie kaum ein anderes Land erholt hat, ist auch ein Erfolg gelungener Innovationspolitik. Doch wir dürfen uns nicht auf den Lorbeeren ausruhen. Die aktuelle europäische Schuldenkrise und das neuerliche Wanken der internationalen Aktienmärkte bedrohen die anziehende Konjunktur.

Damit der wirtschaftliche Erfolg Deutschlands nachhaltig ist, müssen sich die Strukturen weiter verändern, Innovationen benötigen noch mehr Anschub. Denn die Konkurrenz schläft nicht. Asiatische Staaten, insbesondere China und Indien, streben an die Weltspitze und wollen am globalen Wohlstand teilhaben. Betrachtet man die zu erwartende Verteilung der Wirtschaftskraft in 10 bis 20 Jahren, dann erhält man eine eindeutige Botschaft: Die „großen Player" werden China, Indien und nach wie vor Amerika (Nord und Süd) sein. Europa und Russland werden nur noch zusammen eine ähnliche Größenordnung wie China, Indien oder Amerika haben.

Deutschland muss diese Situation als Herausforderung begreifen und darf sich nicht mit dem Status quo zufriedengeben: Wer erfolgsverwöhnt die Zeichen der Zeit verschläft, den bestraft das Leben. Natürlich müssen wir dazu auch ein Bekenntnis

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[1] Vgl. Studie „Deutschland in den Augen der Welt", die im Rahmen des Zukunftsdialogs der Bundeskanzlerin angefertigt wurde [1].

[2] Die folgenden Zitate sind der Broschüre „Deutschland in den Augen der Welt – ausgewählte Zitate" entnommen [1].

zu unseren Stärken entwickeln. Weil wir diese oft nur ansatzweise kennen oder wahrhaben wollen, laufen wir Gefahr zu übersehen, wo unsere Stärken gefährdet sind.

## 1.1 Das Dreieck Kaufmannskunst – Handwerkskunst – Ingenieurskunst

Grundlage der starken deutschen Wirtschaft ist eine historisch verankerte und einzigartige Kombination von Ingenieurwissen, Facharbeit und Kaufmannskunst – ein Know-how, das weltweit nachgefragt wird. Die „Kaufmannskunst" basiert auf der jahrhundertealten Tradition des „ehrbaren Kaufmanns". Sie ist Grundlage für die Entwicklung eines sozialpartnerschaftlichen Kapitalismus, der sich deutlich vom angelsächsischen Modell des Wirtschaftens unterscheidet und die Grundlage der sozialen Marktwirtschaft darstellt. Dieses Primat des Realkapitalismus, des sog. „German Modell" [2–4] ist auch eine Absage an eine Dominanz eines reinen Finanzkapitalismus und ist historisch gesehen eine aus der christlichen Ethik abgeleitete Form eines verantwortbaren Kapitalismus.

Die „Handwerkskunst" bezieht sich auf alle Felder der qualifizierten Facharbeit und hat ihren Ursprung in den Gilden. Die weltweit anerkannte deutsche Facharbeit umfasst dabei heute das gesamte duale berufliche System von Industrie über Handwerk bis zu allen Dienstleistungssparten. Sie ist das unverzichtbare Rückgrat der Leistungsfähigkeit der deutschen Industrie und des deutschen Handwerks – ein Alleinstellungsmerkmal in der Mitte Europas, das in keinem anderen Land der Welt so ausgeprägt ist. Diese Stärke zu verlieren, wäre für Deutschland lebensgefährlich – sie ist aber durch den Mangel an jungen Menschen und die Tendenz zur Über-Akademisierung des beruflichen Lebens gefährdet.

Das „Engineering" bezieht sich nicht nur auf Ingenieure und das Konstruieren und Gestalten neuer Wirklichkeiten, sondern auf die „Fähigkeit des Machens", die aus einem theoretischen Konzept eine realisierte Anwendung macht, sei es in der Technik, in den Dienstleistungen oder in der Gesundheitswirtschaft.

## 1.2 Von „Made in Germany" zu „Enabled by Germany" auf der Basis unserer Familienunternehmen

Im Gegensatz zu manchem anderen hoch entwickelten Land hat Deutschland die Weiterentwicklung von Industrie und Technologie nie vernachlässigt. Die Kombination unserer industriellen Kerne in Verbindung mit Wissens- und Dienstleistungsprodukten ist die entscheidende Grundlage für die Branchen, in denen wir

Weltmarktführer sind. Das hat in der Wirtschaftskrise 2008 geholfen – eine Einzigartigkeit, um die uns inzwischen viele beneiden, die gemeint haben, sie könnten auf die industrielle Basis verzichten.

Das Prädikat „Made in Germany" entwickelt sich dabei zunehmend zur Marke „Enabled by Germany". Deutschland wird zum Spezialisten für die hochkomplexen industriellen und infrastrukturellen Entwicklungsprozesse auf der ganzen Welt, die nachhaltig gestaltet werden müssen. Deutschland kombiniert dabei wie kaum ein anderes Land die traditionellen Tugenden der Verlässlichkeit und Genauigkeit mit Schnelligkeit und Flexibilität und liefert hochspezialisierte Teile, Komponenten und nachhaltige Systemlösungen in die ganze Welt.

Musterbeispiel dafür sind die deutschen Familienunternehmen, von denen der größte Teil eine mittelständische Struktur hat: Unsere Familienunternehmen stellen circa zwei Drittel aller Arbeitsplätze und mehr als 80 % aller Ausbildungsplätze in Deutschland. Es sind gerade diese Unternehmen, die „heimlichen" Weltmarktführer, die das Rückgrat der deutschen Wirtschaft bilden – und auf deren Stärke es auch in Zukunft ankommen wird [5]. Auch diese Einzigartigkeit des Standorts Deutschland wird in keiner Weise in ihrer Bedeutung angemessen wahrgenommen – ist jedoch das entscheidende Rückgrat unserer Wirtschaft und ein zentraler, wenn nicht sogar der zentrale Wettbewerbsvorteil. Zehntausende von solchen Unternehmen mit 50–30.000 Mitarbeitern sind heute in ihren hochspezialisierten Nischen Weltmarktführer oder unter den fünf größten weltweit. Dabei handelt es sich oft um sehr „elementare" Dinge wie Schrauben, Dichtungen, Ventile, Kolben, Spezialsteuerungen für Industrieanlagen, elektrische Steckverbindungen, industrielle Motorwaschanlagen, Bremssysteme, Gartenteichzubehör, Kettensägen usw. Doch wie bewahren wir uns dieses einzigartige Unternehmertum? Woher kommen in Zukunft diese besonderen Unternehmertypen, die unbeirrt ihren Weg gehen, häufig jahrelang an einer Idee feilen und tüfteln, um schließlich mit innovativen Produkten den Weltmarkt zu erobern? Sind es genügend? Werden die „Anfänger" ausreichend von „alten Hasen" unterstützt? Und wie ist es mit dem Generationswechsel? Viele Familienunternehmen haben Schwierigkeiten, eine Nachfolgerin oder einen Nachfolger zu finden. Die Nachfolger brauchen die gleiche Leidenschaft für die Sache und die Menschen wie die Gründer. Ohne diese Leidenschaft und ohne diesen unternehmerischen Innovationsdrang würde unser Land an einem entscheidenden Punkt geschwächt. Mittelfristig würden wir unsere hervorragende Stellung im Weltmarkt einbüßen.

## 2 Deutschlands Gemeinsinn und Wirtschaftsstärke – Zwei feste Standbeine, die es zu erhalten gilt

Unser Land ist von einem enormen Maß an Gemeinsinn und einem starken wertorientierten Engagement geprägt. Das zeigt sich an einer unübersehbaren Vielzahl von Vereinen, Verbänden, Organisationen und kirchlichen Einrichtungen. Diese Dynamik ist auch häufig ein Ausdruck des Ringens um den Zusammenhalt in der Gesellschaft, um ein gelingendes Zusammenleben auf allen Ebenen – in der

Familie und in familienähnlichen Gruppierungen, in der Nachbarschaft, in Betrieben und in zivilgesellschaftlichen Strukturen, zwischen Jung und Alt sowie zwischen Menschen mit und ohne Migrationshintergrund. Dabei gilt es, die strukturelle Überforderung der Familie zu überwinden, den generationsübergreifenden Zusammenhalt zu stärken, der besorgniserregenden Zunahme psychischer Erkrankungen zu begegnen oder durch geeignete Maßnahmen ein langes, gesundes Leben zu fördern[3].

Das andere Standbein ist unsere wirtschaftliche Stärke. Die Einzigartigkeit des deutschen Standorts basiert zu entscheidenden Teilen auf unseren industriellen Kernen. Hieraus hat sich eine große Breite von weltweit gefragten Spezialprodukten, Systemkomponenten und Dienstleistungen entwickelt. Sie ist durch eine hochentwickelte Vielfalt von Familienunternehmen der unterschiedlichsten Größenordnung nachhaltig geprägt – vom Einzelunternehmer über das Handwerk bis hin zu kleinen und mittelgroßen Betrieben. Viele davon sind kleine und große Hidden Champions, Weltmarktführer bei technischen Systemkomponenten und umfassenden Dienstleistungen in unzähligen Spezialgebieten. Wir kombinieren dabei auf besondere Weise qualifizierte Facharbeit mit Ingenieurwissen und sozialpartnerschaftlichen Prinzipien. Auf dieser Basis agieren auch viele große Unternehmen erfolgreich auf dem Weltmarkt.

Die Kombination von ausgeprägtem Gemeinsinn und gelebter Solidarität in Verbindung mit unseren Standortstärken und der Risikobereitschaft der eigentümergeführten Unternehmen darf uns nicht verlorengehen und muss auf allen Ebenen gefördert werden.

## *2.1 Deutschland muss „demografiefest" werden*

Deutschland ist heute nicht nur zuverlässig, genau, pflichtbewusst und innovativ, sondern auch schnell, flexibel und anpassungsfähig geworden. Diese Errungenschaften weiterzuentwickeln ist aber kein Selbstläufer, denn die großen Volkswirtschaften der Schwellenländer holen mächtig auf. Um unsere heutige wirtschaftliche und regional hervorragend verankerte Standortstärke zu erhalten und auszubauen, müssen Arbeit und Arbeitsbedingungen „demografiefest" und zukunftsfähig gestaltet und alle Innovationspotenziale gefördert werden. So muss z. B. die Erfahrung älterer Arbeitnehmer auf betrieblicher Ebene besser genutzt werden. Für die Schaffung einer nachhaltigen Kultur der Selbstständigkeit bedarf es z. B. einer stärkeren Verankerung im Hochschulwesen und verstärkter Anreizsysteme für unternehmerisch handelnde Menschen in allen Lebens- und Berufsphasen.

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[3] Vgl. auch die Ausführung von Sabine Walper zum Thema „Wie wollen wir gemeinsam leben" in [6, S. 12 ff.].

## 2.2 Deutschland braucht ein ganzheitliches Verständnis von Innovation mit Experimentierräumen

Ein weiterer Schlüssel liegt in einer verbesserten Innovationskultur und einem Innovationsverständnis, das nicht nur technische, sondern auch personale und soziale Aspekte integriert. Ein technischer Vorsprung allein verschafft heute selten einen Wettbewerbsvorsprung. Nicht nur Mensch und Technik müssen besser aufeinander abgestimmt werden, auch die Gesellschaft als Ganzes muss auf Innovationen bzw. Innovationssprünge vorbereitet werden, damit sie sich durchsetzen kann. Generell müssen wir in Deutschland unsere Stärke „inkrementeller", feingliedriger Innovationen ausbauen und die Fähigkeit und Bereitschaft zu radikalen Durchbruchsinnovationen entwickeln. Dazu benötigt man die Neugier, Kreativität und ständige Lernbereitschaft aller Beteiligten, die Fähigkeit zur Zusammenarbeit über die Fachrichtungen und Kulturkreise hinweg und die Offenheit einer Gesellschaft, große Innovationssprünge zu wagen.

Für die Gestaltung unserer Zukunft brauchen wir deshalb verstärkt Innovations-Experimentierräume, in denen Kreativität, Risikobereitschaft, Fehlerfreundlichkeit und eine Kultur der Selbstständigkeit eingeübt werden können – und das in allen Lebens und Altersphasen – vom Kindergarten bis ins Rentenalter. Das bedeutet auch innovationshemmende bestehende Regulierungen für Forschung, Arbeitsbedingungen, Steuersysteme, behördliche Zulassungssysteme regional, projektbezogen und/oder zeitlich begrenzt „außer Betrieb" zu nehmen, um solche Experimentierräume überhaupt erst zu ermöglichen.

## 2.3 Deutschland muss die Engergiewende erfolgreich umsetzen

Die Wende in der Energiepolitik und die Wende hin zu einer konsequenten Nachhaltigkeitspolitik sind Beispiele von Zukunftsmärkten, in denen sich für Deutschland große Chancen bieten – wenn wir sie ergreifen. Das sind Gebiete, auf denen große ökonomische und gesellschaftliche Innovationssprünge erforderlich sind. Es sind allerdings auch Gebiete, auf denen die Akzeptanz in der Bevölkerung entscheidend für eine Verbreitung ist. Das Sparen von Energie, ein bewusstes Konsumverhalten, die Mitgestaltung und Akzeptanz von großen Infrastrukturprojekten sind Beispiele für nötige Verhaltensänderungen der Gesellschaft, die staatliche Information und Anreize ebenso erfordern wie individuelle Teilhabe[4]. Dabei ist zu beachten, dass das Nachhaltigkeitspotenzial nicht einseitig auf die Energieerzeugung fokussiert wird, sondern energiesparende Produkte und Dienstleistungen sowie deren Entwicklung in ihrem Nachhaltigkeitspotenzial verstärkt in den Vordergrund kommen.

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[4] Vgl. dazu auch Vorschläge der Arbeitsgruppe „Nachhaltiges Wirtschaften und Wachstum" des Zukunftsdialogs der Bundeskanzlerin [6, S. 84 ff.].

### 2.4 *Die jungen Menschen gehen uns aus – wir dürfen nicht zu Lasten der nächsten Generation leben*

Der Zukunftsdialog der Bundeskanzlerin, der über anderthalb Jahre lief, war eine ausgezeichnete Möglichkeit für die Politik, gemeinsam mit Experten aus der Wissenschaft, Wirtschaft und Zivilgesellschaft nach Lösungen zu suchen, wie wir eine Innovationskultur im Land schaffen. Allen Experten des Zukunftsdialogs war dabei klar: Wir dürfen nicht zu Lasten der nächsten Generationen leben. Wir haben in Zukunft zu wenig junge Menschen. Dies verlangt nicht nur nach entschlossenen Maßnahmen, sondern macht generationengerechte Politik noch dringlicher.

Die Jungen werden die finanzielle Last der sozialen Sicherungssysteme nicht mehr tragen können. Es muss in allen Solidarsystemen eine radikale Schuldenbremse eingeführt werden, die auch die „versteckten" Verschuldungen der öffentlichen Hand aufdeckt, die durch die fehlende Bilanzierungspflicht entstanden sind. Auch wenn wir es nicht wahrhaben wollen: Ältere Menschen (50+) werden (wieder) länger arbeiten können und müssen, damit die sozialen Sicherungssysteme bezahlbar bleiben und der Mangel an jungen Menschen ausgeglichen werden kann. Ein erfolgversprechender Ansatz ist dabei u. a. eine lebensphasenorientierte Arbeitszeitregelung, die den Erwerbstätigen aller Altersgruppen Flexibilität einräumt, um ein engagiertes Arbeiten in allen Lebensphasen, also auch im Alter, zu ermöglichen[5].

Wir brauchen eine konsequente und innovative Familienpolitik, die junge Familien ermutigt, wieder mehr Kinder zu bekommen und dafür auch die finanziellen Voraussetzungen zu haben[6]. Wir müssen ein attraktives Einwanderungsland werden – nach dem Vorbild von Kanada oder Australien. Da die jungen Menschen in unserem Land knapp sind, sind wir auf ein einwanderungsfreundliches Deutschland angewiesen. Und schließlich muss sich dies in einem nachhaltigen Umgang mit Ressourcen niederschlagen, die der nächsten Generation genügend Gestaltungsraum ermöglichen.

## 3 Zentrale Herausforderung: Bildung ausbauen, Bildung exportieren

Deutschland hat in den Augen der Welt mit seinem Bildungssystem einen sehr guten Ruf[7]:

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[5] Vgl. auch Vorschläge der Arbeitsgruppe „Arbeiten im demographischen Wandel" des Zukunftsdialogs der Bundeskanzlerin [6, S. 119 ff.].

[6] Vgl. auch Vorschläge der Arbeitsgruppe „Familie" des Zukunftsdialogs der Bundeskanzlerin [6, S. 14 ff.].

[7] Die folgenden Zitate sind der Broschüre „Deutschland in den Augen der Welt – ausgewählte Zitate" entnommen [1].

> Eine Erklärung der anhaltenden Wirtschaftskraft Deutschlands kann im Bildungssystem liegen. Es ist mit seinem dualen System sehr auf Nachhaltigkeit ausgelegt und gilt als Basis von wirtschaftlichem Handeln.– USA

> Deutschland ist ein ‚Knowledge Power House'. Den Wissensaustausch mit seinen Partnern sollte Deutschland auf internationaler Ebene sehr viel stärker betreiben. – Großbritannien

> Das Ausbildungssystem in Deutschland hat Vorbildcharakter für Indonesien: Lehre, Meisterbrief. Denn hier fehlt ein gut ausgebildeter Mittelbau an Fachkräften. Dies ist ein Exportgut, für das wir uns sehr interessieren. – Indonesien

> Das deutsche Bildungssystem ist vorbildlich. In kaum einem anderen Land kann man seine Kinder mit gutem Gewissen in die öffentlichen Schulen schicken. – Indien

Das Selbstbild von uns Deutschen zu unserem Bildungssystem ist offensichtlich signifikant anders. Es kann aber andererseits nicht so schlecht sein, wie wir es zur Darstellung bringen, sonst wäre nicht erklärbar, warum wir eine so starke Wirtschaftskraft aus unseren Bildungsressourcen bis heute entwickeln. Und geklagt wird seit Jahrzehnten über nichts so sehr wie über Bildung.

## *3.1 Lernen auf allen Ebenen neu zu lernen – unsere Potenziale entfalten*

Ob wir bei der Unterstützung von Familien, der Lösung sozialer Probleme oder der Fähigkeit zur Innovation in Betrieben vorankommen wollen, hier wie da müssen wir die Fähigkeit entwickeln, miteinander und voneinander zu lernen. In der Verbesserung individueller und kollektiver Lernprozesse liegt ein großes soziales und wirtschaftliches Innovationspotenzial.

Dies beinhaltet zunächst die Potenzialentfaltung jedes Einzelnen an allen Lernorten der Gesellschaft – von Familien und Kindertagesstätten, Schulen und Universitäten, Unternehmen und öffentlichen Verwaltungen bis hinzu Vereinen und Clubs[8]. Wie gelingt es uns, dass jeder Bürger sein Potenzial in allen Lebensphasen entfalten kann? Jeder – das heißt auch Jugendliche ohne Ausbildung oder die Generation der über 70-Jährigen. Dazu benötigen wir eine grundsätzliche Veränderung der Lernbereitschaft und Lernkultur. Dies geschieht zwar schon an vielen Orten, aber eben noch nicht überall. Ein sehr wichtiger Aspekt, der sich in fast allen Arbeitsgruppen des Zukunftsdialogs bemerkbar machte, ist: Es muss sich endlich etwas ändern in den Bildungssystemen – hin zu einer neuen Aufgabenteilung zwischen Bund, Ländern, Kommunen und privaten Trägern. Die überwiegende Zuständigkeit der Länder muss dabei dringend überwunden werden.

[8] Vgl. dazu auch Vorschläge der Arbeitsgruppe „Potentialentfaltung und selbstverantwortliche Lebensgestaltung" des Zukunftsdialogs der Bundeskanzlerin [6, S. 133 ff.].

## 3.2 Jede Form von Qualifikation und Kompetenz muss zu einer Anerkennung führen

Nicht zuletzt benötigen wir eine bessere Wertschätzung für jede Form von Qualifikation und Kompetenz – unabhängig davon, ob sie formal oder informell erworben wurden. Wir sehen in der Möglichkeit eines Nachweises informeller Qualifikationen, z. B. in Form eines Kompetenzpasses einen Schlüssel dafür, dass Menschen mit einfachen Qualifikationen oder ohne formale Abschlüsse bessere Chancen auf dem Arbeitsmarkt erhalten[9]. Dabei muss der Stellenwert des „Lernens im Prozess der Arbeit“ genau den gleichen Rang und Wert erhalten wie die formale berufliche Weiterbildung. Das gilt aber auch für Umschulungswege, wenn sich Menschen in Lebensphasen nach dem Alter von circa 30 Jahren entschließen einen anderen Beruf anzustreben. Hier sind die meisten derzeitigen Bildungsprozesse für die Betroffenen nicht passgenau, oft wegen der Familiensituation nicht bezahlbar oder viel zu sehr von den grundständigen Bildungsgängen abgeleitet. Hier müssen die Kompetenzentwicklungsprozesse in den laufenden Arbeitsprozess im neuen Berufsfeld integriert werden.

## 3.3 Nicht-akademische Facharbeit muss viel stärker in den Mittelpunkt des Handelns

Entgegen aller Unkenrufe sind unsere Stärken in der anwendungsorientierten Forschung und Entwicklung im weltweiten Vergleich nach wie vor deutlich. Doch sie liegen genauso im dualen Berufsausbildungssystem, das unsere einzigartige Stellung durch qualifizierte Facharbeit in Handwerk, Industrie und Dienstleistungen gewährleistet. Da lässt sich ein viel größeres Problem erkennen als bei der Suche nach qualifizierten Ingenieuren oder Ärzten. Wir haben derzeit einen unguten Trend, dass am besten alle Akademiker werden sollen – und genau das geht zu Lasten qualifizierter Facharbeit. Wir sind gerade dabei, vermehrt arbeitslose Akademiker zu produzieren, während wir eigentlich gut ausgebildete Facharbeiter für moderne, technikgetriebene Berufe wie Mechatroniker, Installateur oder Schweißer bräuchten, ganz zu schweigen von Dienstleistungsberufen, zum Beispiel in Pflegebereich oder Kindergärten. Junge Menschen müssen wieder verstärkt für die international hoch anerkannten deutschen beruflichen Ausbildungswege begeistert werden. Es gilt, die Attraktivität der Arbeit in Deutschland sichtbar zu machen, um qualifizierte Kräfte im Land zu halten und international qualifizierte Arbeitnehmer zu gewinnen.

[9] Vgl. dazu auch Vorschläge der Arbeitsgruppe „Berufliches und Lebenslanges Lernen“ des Zukunftsdialogs der Bundeskanzlerin [6, S. 150 ff.].

## 3.4 Berufliche Bildung in den Schulen und Hochschulen verankern

Infolgedessen muss sich Deutschland für eine verbesserte Wertschätzung der nicht-akademischen Facharbeit einsetzen[10]. Wir müssen diese Berufsfelder attraktiver gestalten und darüber diskutieren, wie sich das flächendeckend schon in der Schule und Hochschule verankern lässt. Eine Mindestforderung ist die Möglichkeit, dass Schüler bzw. Studierende in allen Phasen, Bereichen und Fachdisziplinen parallel zu ihrer schulischen bzw. akademischen Ausbildung einen beruflichen Bildungsabschluss erwerben können. In vielen Bereichen sollte man das sogar zur Pflicht machen. Damit würde auch eine neue Wahlfreiheit des Wechsels zwischen qualifizierter Facharbeit und akademischer Tätigkeit ermöglicht werden.

## 3.5 Die Marke „Duale Aus- und Weiterbildung“ kann ein Exportschlager werden

Der internationale Wettbewerbsdruck sowie der demografische Wandel erfordern, dass das lebenslange Lernen für alle Qualifikationen eine Realität wird. Die betriebliche Erfahrung zeigt: Je betriebs- und arbeitsplatznäher Weiterbildung und Kompetenzentwicklung erfolgen, desto besser werden sie akzeptiert und desto effektiver sind sie. Deshalb müssen wir die international anerkannte Marke der „Dualen Ausbildung“ zu einer Marke „Duale Aus- und Weiterbildung“ weiterentwickeln[11]. Das permanente Lernen im Job und die Kompetenzentwicklung des Einzelnen müssen zur Selbstverständlichkeit werden. Zugleich braucht unser berufliches Bildungssystem eine neue Wertschätzung der nicht-akademischen Arbeit. Sie ist ein wesentlicher Teil unserer Stärken im internationalen Wettbewerb. Das könnte ein Exportschlager werden.

In diesem Zusammenhang stellt sich die Frage: Warum exportieren wir nicht generell Bildung und zwar von der beruflichen bis zur akademischen Bildung? Warum verkaufen wir Bildung nicht wie Schrauben? Zumal genügend konkrete Anfragen vorliegen. Boom-Staaten wie Indien stehen heute vor der großen Herausforderung, breiten Bevölkerungsschichten eine Schulbildung zu ermöglichen. Das wäre eine Aufgabe für Deutschland. Da fehlt es uns noch an Schlagkraft im amerikanischen Stil.

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[10] Vgl. dazu auch Vorschläge der Arbeitsgruppe „Einzigartigkeit und Standortidentität“ des Zukunftsdialogs der Bundeskanzlerin [6, S. 93 ff.].

[11] Vgl. dazu auch Vorschläge der Arbeitsgruppe „Zukunft der Arbeit“ des Zukunftsdialogs der Bundeskanzlerin [6, S. 84 ff.].

## 4 Die Digitalisierung unserer Welt steht erst am Anfang – Wir sind gefordert

Alle diese Lernprozesse erhalten durch die Digitalisierung des Privatlebens wie der Arbeitswelt eine besondere Brisanz. Der Innovationssprung von der analogen in die digitale Welt verändert mit einer atemberaubenden Geschwindigkeit nicht nur unsere Informations- und Dienstleistungsprozesse, sondern auch den Alltag und die meisten „Alltagsprodukte". Das Internet ist für viele ein Lebensraum geworden.

Das „Internet der Dinge", die digitale Steuerung und Vernetzung von Informationen, wird zunehmend Alltags- und Gebrauchsgeräte erfassen: „Denkende Stoßstangen" werden sich in ihren Materialeigenschaften an die Verkehrssituation anpassen, „sprechende Kühlschränke" Einkaufslisten vorlesen und automatisch Einkäufe im Internet vornehmen. Analog zur Einführung der Buchdruckerkunst handelt es sich bei der Digitalisierung um eine globale Umwälzung, die alle Lebensbereiche weitreichend beeinflusst und uns vor neue Kompetenzanforderungen stellt: Jung und Alt brauchen Kenntnisse im Umgang mit dem Internet, z. B. für den Schutz der Privatsphäre. Selbst traditionelle Handwerks- Ausbildungsgänge müssen modernisiert werden, man denke nur an den Dachdecker, der neben Ziegeln und Wettersensoren auf Dächern die Installation der Solarkollektoren ausführt.

### *4.1 Der „Homo Zappiens" kommt – Wir müssen umdenken*

Die Digitalisierung der Lebenswelten wird insbesondere den Bildungsbereich erfassen und umwälzen. Die jüngere Generation und die heranwachsenden Kinder haben sich an diese neue Welt in ihrem Lernverhalten im Sinne einer Evolution schon angepasst. Der Homo Zappiens[12] kommt. Das bedeutet: Eine Generation wächst heran, die von Kindesbeinen an eine extrem hohe Parallelitätskompetenz hat, in extremem Umfang „multitasking" ist, kollaborativ schon als Kleinkind in den weltweiten Spielnetzen „arbeitet", über das interaktive Spiel lernt und mit der Internet Technologie als „Freund des Lebens" aufwächst. Auch die Leseorientierung hat sich geändert. Lesen erfolgt erst über Icons und Bildmuster, die nicht mehr von oben links nach unten rechts, sondern als Musteridentifikation verfolgt werden. Demgegenüber bleiben herkömmliche Fähigkeitsmuster auf der Strecke – sich z. B. auf eine Aufgabe über einen langen Zeitraum zu konzentrieren, Lesefähigkeiten von Text, etc. Aber diese Generation hat sich bereits an die Anforderungen einer Gesellschaft angepasst, die von Informationen aller Art überflutet wird. Sie lebt im Netz, sie wohnt im Netz. Der Begriff „Digital Residents" gibt diesen Zusammenhang deutlich wieder und betrifft längst schon nicht mehr die junge Generation allein, sondern erfasst zunehmend

[12] Der Begriff „Homo Zappiens" wurde 2006 von dem niederländischen Wissenschaftler Wim Veen eingeführt. Seine Thesen wurden in zahlreichen Schulversuchen bestätigt.

alle Altersgruppen bis in die Altersheime, in denen sich völlig neue Möglichkeiten der weltweiten Kommunikation eröffnen.

Auf diese Herausforderung hat das Bildungssystem insbesondere im vor- und schulischen Bereich und ebenso in der beruflichen wie akademischen Bildung nicht oder völlig unzureichend reagiert. Nicht die heranwachsende Jugend mit ihrer „Parallelitätskompetenz“ trägt die Schuld, sondern die Akteure im Bildungssystem sind ihren Pflichten nicht nachgegangen.

Dabei liegen einschlägige reformpädagogische Erfahrungen des kollaborativen und projektorientierten Lernens, des „Learning by doing“, und der außerschulischen Lernorte in ausreichender Menge vor. Was fehlt, ist ein flächendeckender Paradigmenwechsel des Bildungssystems zu kollaborativem, vernetzem Lernen in allen Fächern und Disziplinen. Das gilt ebenso für Schulbuchverlage, die Vernetzung von Betrieben und Schulen oder die Verknüpfung der Ausbildungsprozesse an Universitäten, z. B. durch weltweit organisierte Lehr- und Tutorennetzwerke.

## 5 Zukunftsszenario „Deutschland 2035“

Betrachtet man die Herausforderungen der nächsten zwei Jahrzehnte zusammenfassend, so lässt sich feststellen, dass wir eine große Chance haben, im internationalen Wettbewerb weiter zu bestehen und unseren Wohlstand und unser Wohlergehen weiter zu erhalten.

Was könnte dafür ein Leitbild sein? Vielleicht ist es die Idee, dass wir 2035 weltweit als ein Land gelten, in dem es sich lohnt zu leben, alt zu werden, und ein Land, das in der Vielfalt seiner Strukturen ein Exportschlager ist. Im Jahr 2035 könnte die Nachfrage nach Bildungsdienstleistungen rund um die Welt den Export von Teilen, Komponenten und Systemen ergänzt haben, der nach wie vor die industrielle Basis Deutschlands darstellen wird. Die ersten „Mega-Cities“ dieser Welt haben mit unserer Hilfe ein neues Gesicht bekommen[13]. Das Konzept der Umgestaltung von Industrielandschaften, also der Export des „Konzepts Ruhrgebiet“, soll nun nicht nur auf Shanghai, sondern auch auf Moskau angewandt werden. Nur London zögert noch mit einem Auftrag.

Die Verfahren zu einer frühzeitigen Bürgerbeteiligung, bei denen über Deutschland gelacht wurde, sind heute ein Exportartikel[14]. „Stuttgart 21“ ist überall zu finden. Es liegen sogar Anfragen aus New York vor. Die Piratenpartei hat sich – wie 2012 die Grünen – etabliert und stellt in Berlin den Oberbürgermeister. Berlin ist zum Zentrum digitaler Plattformen für Unterrichtsmaterialien und Fernstudien geworden. Deutschland hat es diesmal geschafft, den Big Playern aus den USA den Rang abzulaufen, weil die Lernmodule und -inhalte einfach besser sind. Einen

[13] Vgl. dazu auch Vorschlag 8 der Arbeitsgruppe „Einzigartigkeit und Standortidentität“ des Zukunftsdialogs der Bundeskanzlerin [6, S. 97].

[14] Vgl. dazu auch Vorschläge der Arbeitsgruppe „Chancen und Risiken der Bürgerbeteiligung“ des Zukunftsdialogs der Bundeskanzlerin [6, S. 45 ff.].

deutlichen Rückgang hat die Arbeitslosigkeit mit der endgültigen Privatisierung der Arbeitsagenturen erlebt. Insbesondere das Provisionssystem für die Vermittler hat in kurzer Zeit zu einer Erhöhung der Vermittlungsquoten geführt.

Das demografische Problem hat 2035 China mit voller Breitseite erreicht. Deutschland hat es 2035 geschafft, sein Demografie-Problem zu lösen. Ältere arbeiten wieder länger, die 2015 eingeführte flexible Lebensarbeitszeit hat zur Folge, dass die Menschen im Durchschnitt erst mit 70 in Pension gehen[15]. Deutschland exportiert die sozialen Konzepte von generationsübergreifender Zusammenarbeit, beispielsweise Mehrgenerationen-Häuser, in alle Ballungszentren Chinas. Deutsche Sozialarbeiter sind gefragt wie noch nie.

Die Schulen in Deutschland sind – wie 2012 die Universitäten – inzwischen zum größten Teil in Körperschaften des öffentlichen Rechts übergegangen. An vielen Orten haben sich örtliche Unternehmen am Betriebskapital beteiligt. Analog zu den Hochschulen werden die Schulen an ihrem Output gemessen. Die Landes- und Bundesbehörden dürfen nicht mehr in die Schulen hineinregieren. Ermöglicht wurde dies durch die Aufhebung der ausschließlichen Länderzuständigkeit im Jahre 2020.

Der Bund hat dann in den folgenden Jahren mit erheblichen Investitionsmitteln diese Umstrukturierung ermöglicht. Besonders in den USA besteht nun Nachfrage, wie man die dortigen Privatschulen und die vernachlässigten öffentlichen Schulen zusammenführen könnte. Ein erster Großauftrag ist 2035 gerade an ein deutsches Bildungsunternehmen vergeben worden.

In Indien hat ein deutsches privatwirtschaftliches Bildungsunternehmen die ersten 10.000 Gymnasien nach deutschem Vorbild aufgebaut. 50.000 ältere deutsche Lehrer unterrichten inzwischen an diesen Schulen mit einem reformpädagogischen Konzept, das an die indischen Verhältnisse angepasst wurde. Es handelt sich um den größten Auftrag, der je an ein deutsches Bildungsunternehmen vergeben wurde.

Inzwischen ist das duale Aus- und Weiterbildungssystem in 20 Schwellenländern erfolgreich eingeführt worden. Deutsche Experten mit nicht-akademischem Berufshintergrund sind gefragter als die deutschen Akademiker. Der Anteil der Akademiker in Deutschland hat sich ohnehin bei circa 60 % eingependelt, weil die nicht-akademische Facharbeit inzwischen wieder die gleiche Wertschätzung genießt wie die akademische Ausbildung. Überraschend ist auch, wie sehr die privatwirtschaftlichen internationalen Universitäten eingeschlagen haben. Seit die gestaffelten Studiengebühren analog zum englischen System eingeführt wurden, boomt der Universitätsmarkt. An einer der neu gegründeten, auf Asien spezialisierten Maschinenbau-Universitäten schreiben sich bei einer jährlichen Studiengebühr vom 50.000 € pro Jahrgang 800 Studierende ein, die überwiegend aus China kommen.

Die Geburtenrate ist nach einem Minimum im Jahr 2020 kontinuierlich gestiegen und liegt 2035 bei einem Durchschnitt von 2,5 Kindern pro Familie. Die vielen Aktionen und Maßnahmen zur Stärkung von Ehe und Familie haben Früchte getragen.

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[15] Vgl. Vorschlag 5 der Arbeitsgruppe „Arbeiten im demographischen Wandel“ des Zukunftsdialogs der Bundeskanzlerin [6, S. 122].

Das Bundesmodellprojekt für abgestimmte lokale Zeittakte[16], also die Anpassung von Betriebszeiten, öffentlichen Einrichtungen, Ämtern, Schulen, Kindergärten, Bahnen und Bussen an die Bedürfnisse der Familien war 2020 ein durchschlagender Erfolg und ist 2035 in fast allen Regionen Deutschlands eingeführt. So wurde z. B. auch die Bauordnung geändert, die verpflichtend Kinderwagenplätze an Fahrradabstellplätzen mit Lademöglichkeit für die Elektromobilität innerhalb von Mietshäusern vorschreibt.

Der Tourismus nach Deutschland hat 2035 bisher unbekannte Ausmaße angenommen. Es ist gelungen, eine bundesweite zentrale Plattform aufzubauen, die weltweit auf die junge Generation ausgerichtet ist[17]. Die deutsche „Kleinstaaterei" im Tourismus wurde überwunden.

Deutschland ist bei den jungen Menschen weltweit sehr begehrt: Da muss man gewesen sein. Das hat dazu geführt, dass Deutschland 2035 kein Fachkräfteproblem mehr hat, weil auch aus den hochentwickelten Ländern wie den USA junge Menschen nach Deutschland einwandern wollen.

Besonders attraktiv ist Deutschland für junge Familien wegen seines Bildungssystems geworden. Wegen der extrem schnellen und unbürokratischen Eingliederung, von Wohnungsbeschaffung bis zum Kindergartenplatz und mehrsprachigen Schulen, hat Deutschland 2035 zum ersten Mal vor Kanada und Australien den ersten Platz als einwanderungsfreundlichstes Land der Welt erreicht.

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[16] Vgl. auch Vorschlag 2 der Arbeitsgruppe „Familie" des Zukunftsdialogs der Bundeskanzlerin [6, S. 16].

[17] Vgl. dazu auch Vorschlag 14 der Arbeitsgruppe „Einzigartigkeit und Standortidentität" des Zukunftsdialogs der Bundeskanzlerin [6, S. 100].

# Innovative XXL-Lehre: Das Beispiel „Kommunikation und Organisationsentwicklung“ der RWTH Aachen

**Daniela Janßen, Stefan Schröder und Ingrid Isenhardt**

**Zusammenfassung** In den letzten zehn Jahren haben tiefgreifende Veränderungen in der Hochschullehre stattgefunden. Unterschiedliche Strömungen, z. B. die Vermittlung überfachlicher Kompetenzen, ein verändertes Mediennutzungsverhalten der heutigen Schulabsolventen und -absolventinnen sowie steigende Studierendenzahlen haben Einfluss auf die Gestaltung der Hochschullehre genommen. Aufgrund der veränderten Umstände ist eine Anpassung der Lehrmethoden und -konzepte erforderlich. Studierende rücken dabei ins Zentrum des Lehr- und Lernprozesses. Besonders für Lehrveranstaltungen mit großen Hörerzahlen ist dies eine besondere Herausforderung. Am Beispiel der Lehrveranstaltung „Kommunikation und Organisationsentwicklung“ des Zentrums für Lern- und Wissensmanagement (ZLW) der RWTH Aachen University wird aufgezeigt, wie die Vorlesung ein vollständiges Redesign erfahren hat, um den veränderten Rahmenbedingungen und Anforderungen gerecht zu werden.

**Schlüsselwörter** Überfachliche Kompetenzen · Engineering Education · Audience Response System · Best-practice

## 1 Einleitung

In diesem Beitrag wird ein Best-Practice Beispiel vorgestellt, das vor dem Hintergrund verschiedenster Einflussfaktoren im gesamten universitären Lehrprozess innovative Lehrmethoden und -konzepte umsetzt. Studierende rücken dabei ins Zentrum ihres Lernprozesses, insbesondere bei Lehrveranstaltungen mit großen Hörerzahlen. Am Beispiel der Lehrveranstaltung „Kommunikation und Organisationsentwicklung“ des Zentrums für Lern- und Wissensmanagement (ZLW) der RWTH Aachen University wird aufgezeigt, wie die Vorlesung ein vollständiges

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Redesign erfahren hat, um den veränderten Rahmenbedingungen und Anforderungen aller am Wertschöpfungsprozess „Lehre“ beteiligten Stakeholdern gerecht zu werden.

## 2 Veränderte Einflussfaktoren im Kontext der Hochschullehre

In den letzten zehn Jahren haben tiefgreifende Veränderungen in der Hochschullehre stattgefunden. Unterschiedliche Strömungen haben Einfluss auf die Gestaltung der Hochschullehre genommen. Zu diesen zählen u. a. der Fokus auf die Vermittlung überfachlicher Kompetenzen, das veränderte Mediennutzungsverhalten [1] der heutigen Schulabsolventen und -absolventinnen sowie die Vielzahl von Studierenden an deutschen Hochschulen. Diese wichtigsten Einflussfaktoren werden im Folgenden näher erläutert.

### *2.1 Überfachliche Kompetenzen*

Die Vermittlung von überfachlichen Kompetenzen spielt in der Hochschullehre im Allgemeinen und in den Ingenieurstudiengängen im Speziellen eine zentrale Rolle. Nicht nur Fachwissen wird heutzutage von Ingenieuren und Ingenieurinnen erwartet – dieses wird weitgehend als selbstverständlicher Output der Universität vorausgesetzt -, sondern vor allem auch überfachliche Kompetenzen wie Methoden, Selbst-, Organisations- und Sozialkompetenzen [2].

Das ZLW hat bereits seit langem aus seinem interdisziplinären und ganzheitlichen Ansatz heraus bei der Konzeption und Durchführung der Lehrveranstaltungen den Anspruch, Lehre so zu gestalten, dass zusätzlich die Vermittlung überfachlicher Kompetenzen im Fokus steht. Unterstützt bzw. implementiert wird dies im Curriculum durch den Bologna Prozess [3]. Ein Kernziel der Reform ist es, die Beschäftigungsfähigkeit („Employability“) von Hochschulabsolventen und Hochschulabsolventinnen zu fördern [4]. Studierende sollen demnach so ausgebildet werden, dass sie dem Arbeitsmarkt schnell, effizient und adäquat ausgebildet zur Verfügung stehen [5].

Zudem setzt sich der Paradigmenwechsel „shift from teaching to learning“ [6], also die zunehmend studierendenzentrierte und beteiligungsorientierte Gestaltung der Lehre, immer mehr in der Praxis durch: „It is characterized by innovative methods of teaching which aim to promote learning in communication with teachers and other learners and which take students seriously as active participants in their own learning, fostering transferable skills such as problem-solving, critical thinking and reflective thinking“ [7]. Die Gestaltung der Lehre orientiert sich nun vielmehr an „Learning Outcomes“, also an den Lernergebnissen von Studierenden und deren Erreichung als an der „Content-Orientierung“, d. h. der Vermittlung von Inhalten.

## 2.2 Digital Natives – der Student von heute?!

Für eine studierendenorientierte Gestaltung von Lehrveranstaltungen ist es für Lehrende von zentraler Bedeutung, die Zielgruppe - die Studierenden - zu kennen und sie aktiv in die Lehrveranstaltung einzubinden [8]. Die heutige Generation von Jugendlichen wird häufig als „Digital Natives“ [9] bezeichnet. Digital Natives sind „[. . . ] Menschen [. . . ], die nach 1980 direkt in das digitale Zeitalter hineingeboren wurden, [ . . . ]. Sie sind durchweg vernetzt und mit den neuen digitalen Medien und Möglichkeiten bestens vertraut.“ [10]. Hier wird die zentrale Rolle von neuen und sozialen Medien wie beispielsweise Blogs, Foren oder sozialen Netzwerken für die Studierenden deutlich. Neue technologische Entwicklungen begünstigen diesen Trend zusätzlich. Neue Medien wie Audience Response Systeme (ARS) bieten an dieser Stelle sowohl die technologischen als auch die didaktischen Möglichkeiten, um Studierende in Lehrveranstaltungen einzubeziehen und mit ihnen in Interaktion zu treten [11]. Vor diesem Hintergrund ist heutzutage von einem anderen Mediennutzungsverhalten der Studierenden auszugehen. Sie bringen einerseits andere Voraussetzungen mit als Studierende, die vor den 1980er Jahren geboren sind der 1990er Jahre und haben gleichzeitig andere Ansprüche an die Gestaltung der Lehre in Hinblick auf den Einsatz von neuen und sozialen Medien [1].

Der Bedarf nach Einsatz neuer Medien im Kontext der Hochschullehre spiegelt sich im Ideenwettbewerb von TeachING-LearnING.EU (siehe Teaching-Learning.EU, http://www.teaching-learning.eu/aktuelles/ideenwettbewerbe.html) wider. Studierende der Ingenieurwissenschaften können durch die Einreichung eigener Ideen aktiv an der Verbesserung der Lehre und des Lernprozesses ingenieurwissenschaftlicher Studiengänge mitwirken. Die eingereichten Ideen zeigen die Forderung nach neuen technologischen Möglichkeiten wie sozialen Netzwerken, der Aufzeichnung von Lehrveranstaltungen, der Nutzung von Lehrportalen zur Bereitstellung von Lernmaterialien und Skripten. Die Vermittlung überfachlicher Kompetenzen ist nicht nur ein Ziel von Bologna, sondern wird ebenso in den eingereichten Ideen der Studierenden gewünscht.

## 2.3 Steigende Studierendenzahlen

Der steigende Bedarf an Ingenieuren und Ingenieurinnen [12] und damit einhergehend die steigende Anzahl von Studienanfängern und Studienanfängerinnen stellt ingenieurwissenschaftliche Studiengänge vor die Herausforderung, in Lehrveranstaltungen mit einer großen Zahl an Studierenden umgehen zu müssen bzw. auch zu können. Dieses Problem wird zusätzlich durch die Verkürzung der Schulzeit um ein Jahr im Zuge der Schulreform verschärft. 2013 steht der doppelte Abiturjahrgang an, weswegen die Zahl der Einschreibungen an deutschen Universitäten deutlich steigen wird. Der Wegfall der Wehrpflicht begünstigt diese Entwicklung zusätzlich. Dies hat zur Folge, dass neue Interaktionsmöglichkeiten für die Studierenden im Rahmen „klassischer“ Lehrveranstaltungen mit großen Hörerzahlen geschaffen und implementiert werden. Hierzu bedarf es ebenso geeigneter technischer Lösungen, wie entsprechend neu aufbereiteter Inhalte.

Zusammengefasst ergeben sich für das Lernverhalten, aber auch das Lehrkonzept neue Anforderungen sowie Möglichkeiten, die mit steigenden Hörerzahlen, wachsenden (überfachlichen) Anforderungen von Seiten der Wirtschaft und der Vielfalt medientechnischer Lösungen umgehen müssen, wie zum Beispiel: Die Ansprache der Studierenden über verschiedene Kanäle und der angepasste Zugang zum Lehrstoff:

- Interaktive Angebote, die individuelle Lernprozesse, -wege und -geschwindigkeiten zulassen
- Mitgestaltung der Inhalte mit praxis- und projektbasierter Ausrichtung neben reiner Wissensvermittlung

Im Folgenden wird unser Versuch, diesen Bedarfen und Ansprüchen in der Lehrveranstaltung „Kommunikation und Organisationsentwicklung" durch Neukonzipierung gerecht zu werden, vorgestellt.

## 3 Redesign der Vorlesung „Kommunikation und Organisationsentwicklung"

### *3.1 Umsetzung des neuen Lehrkonzepts*

Die Erstsemester-Pflichtveranstaltung „Kommunikation und Organisationsentwicklung" (KOE) wird unter Verantwortung der promovierten Soziologin und habilitierten Maschinenbauerin Ingrid Isenhardt organisiert und durchgeführt. Insgesamt besuchen ca. 1200 Studierende, größtenteils des Maschinenbaus, die Veranstaltung. Neben der wöchentlich stattfindenden Vorlesung findet zusätzlich eine Laborübung statt, die den Studierenden die Simulation eines Unternehmens und dadurch die direkte Erprobung in einer möglichst authentischen Umgebung ermöglicht. Unter den eingangs dargelegten veränderten Einflussfaktoren und der Prämisse der Lernerfolgsmaximierung sowie der nachhaltigen Vermittlung von praxisrelevanten und überfachlichen Inhalten wurde die Vorlesung kontinuierlich weiterentwickelt und im Wintersemester (WS) 2012/2013 einem kompletten Redesign unterzogen. Dabei wurden neue lern- und lehrdidaktische Elemente implementiert bzw. bestehende weiter ausgebaut. Die Veranstaltungselemente sind in Abb. 1 visualisiert und werden folgend erläutert (im WS 2012/2013 neu eingesetzte Elemente sind mit einem * gekennzeichnet).

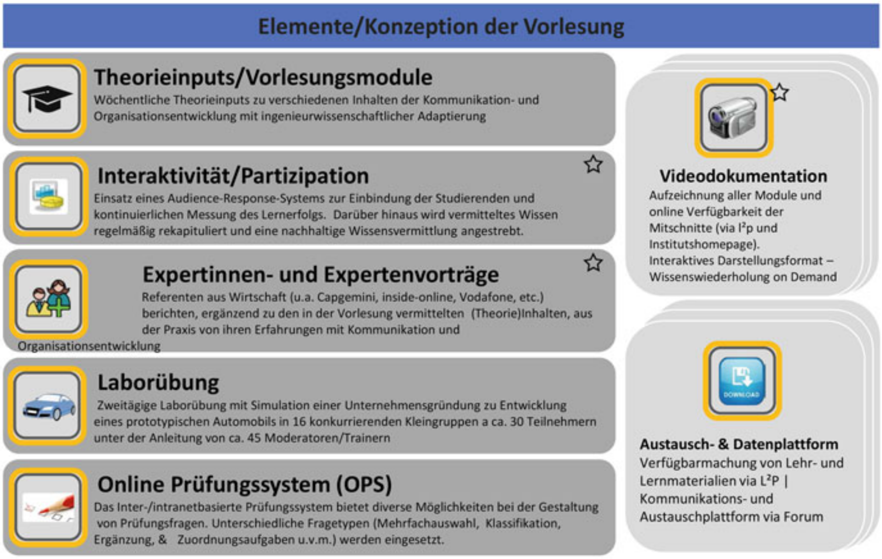


**Abb. 1** Struktur der Vorlesung „Kommunikation und Organisationsentwicklung" der RWTH Aachen University [Eigene Darstellung]

### *3.2 Theorieinput & Vorlesungsmodule*

Insgesamt besteht die Vorlesung aus zwölf Modulen, von den Grundlagen der Kommunikation- und Organisationsentwicklung, Lern- und Wissensmanagementkonzepten und interkulturellen Aspekten weltweiter Arbeitsteilung über Management- sowie systemtheoretische Ansätze bis hin zu Praxisbeiträgen verschiedener Expertinnen und Experten aus Wirtschaft und Wissenschaft (siehe Expertenvorträge in Abb. 1). Das gesamte Lehrkonzept folgt dabei einer streng linearen Struktur (siehe Abb. 2). So knüpfen beispielsweise die Praxisvorträge an bereits vermittelte Theorieinhalte an, greifen diese auf und schaffen so den idealtypischen Transfer von Theorie und Praxis.

Am Ende eines jeden Moduls werden die Vorlesungsinhalte auf den modulrelevanten Rekursionsebenen reflektiert und resümiert. Hierzu wird der KOE-Trichter eingesetzt (siehe Abb. 3), der auf sowohl die systemische Sichtweise (auf der linken Seite des Trichters) als auch die unterschiedlichen Unternehmensebenen aufgreift (auf der rechten Seite des Trichters). Dabei werden Kommunikation und Organisationsentwicklung als entscheidende Entwicklungsstränge der Gestaltung der Interaktion von Mensch, Organisation und Technik auf unterschiedlichen organisationalen Ebenen (z. B. innerhalb von Abteilungen oder in Projektteams) reflektiert.


**Abb. 2** KOE Vorlesungstreppe [Eigene Darstellung]

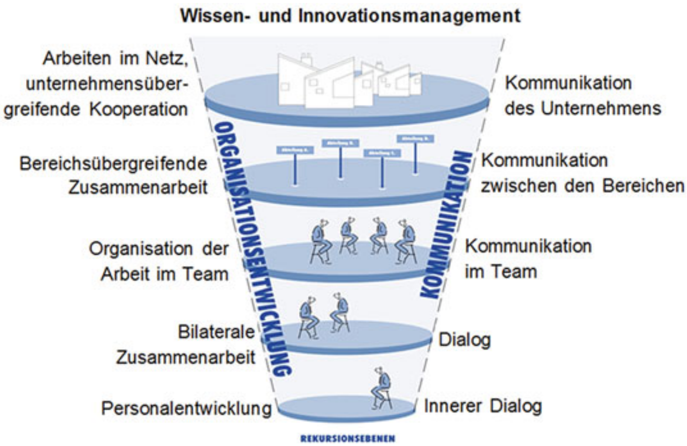


**Abb. 3** KOE Trichter/Rekursionsebenen [Eigene Darstellung nach 18]

## *3.3 Interaktivität durch Einsatz eines „Audience Response System“*

Um den Bedarfen der Studierenden, beispielsweise hinsichtlich interessensgerechter Informationsvermittlung gerecht zu werden, wird seit dem WS 2012/2013 ein Audience Response System (ARS) eingesetzt (Online Abstimmungstool zum Einbeziehen


**Abb. 4** Exemplarische ARS Darstellung [Eigene Darstellung | polleverywhere.com]

des Auditoriums). Den Studierenden wird dadurch mehrfach (ca. 2–3 Mal) ermöglicht, aktiv in die Vorlesung einzugreifen und z. B. (Teil-)Inhalte auszuwählen, Wissen gezielt zu rekapitulieren, zu interpretieren und zu reflektieren oder sich auf mögliche Klausurfragen vorzubereiten (siehe Abb. 4). Dabei werden die Taxonomien von Lernzielen, wie z. B. wissen, verstehen, anwenden und analysieren [18, 14], durch beispielsweise Wissens- und Verständnisfragen, sowie Anwendungsbeispiele nahezu ganzheitlich adressiert, was zur Folge hat, dass Problemlösungskompetenzen der Studierenden gefördert werden. Die Teilnahmebarrieren für die Studierenden sind denkbar gering. Benötigt werden ein internetfähiges Endgerät (Smartphone, Laptop) und eine funktionierende Internetverbindung (z. B. eduroam).

## *3.4 Expertinnen- und Expertenvorträge*

Wie eingangs bereits erwähnt, strebt das Redesign der Vorlesung einen erhöhten Relevanz- und Praxisbezug für die Studierenden an und erhöht gleichzeitig die Fähigkeit, das Arbeits- und Berufsleben in seiner Komplexität zu verstehen. So geben mehrere renommierte Gastredner aus der Industrie (darunter u. a. Vertreter der Unternehmen Vodafone Group, Inside Unternehmensgruppe, Capgemini und der p3 Ingenieurgesellschaft) Einblicke in ihre Unternehmen und Berufserfahrungen. Inhaltlich thematisieren die Experten beispielsweise ihre Erfahrungen im Rahmen internationaler Projektarbeit (Thema weltweite Arbeitsteilung & kulturelle Diversität bei Offshore Projekten mit/in Indien) und interdisziplinärer/fachkultureller Herausforderungen (Thema interkulturelle Zusammenarbeit am Beispiel des Projektes Airbus). Dabei schlagen diese gleichsam die Brücke zwischen bereits vermittelten theoretischen Inhalten und der Relevanz von Kommunikation und Organisationsentwicklung im täglichen Arbeitsprozess. Darüber hinaus vermitteln die Experten wichtige essentiell-notwendige überfachliche Kompetenzen, die weit über die rein fachliche Qualifikation der ingenieurwissenschaftlichen Studierenden hinausgehen, beispielsweise Sozial-, Selbst- und Methodenkompetenz. Um dem Spannungsfeld zwischen der Vermittlung von wissenschaftlichen Grundlagen und praxisbezogener Lehrform gerecht zu werden [15], wurde auf eine adäquate Inhalts- und Grundlagenverteilung geachtet (nicht zu Lasten unzureichender wissenschaftlicher Grundlagen).

### *3.5 Laborübung*

Beim Thema Kommunikation und Organisationsentwicklung versteht es sich von selbst, dass nicht alle Vorlesungsinhalte und Lernziele zur Wissensvermittlung in Großvorlesungen geeignet sind bzw. nicht internalisiert werden können. Daher findet vorlesungsbegleitend einmal im Semester an 1,5 Tagen zusätzlich eine Laborübung statt, in der es den Studierenden möglich ist, zuvor theoretisch vermittelte Grundlagen praktisch in Form einer Unternehmenssimulation (simulation-based-learning) anzuwenden und sich in Kommunikations- und Arbeitsprozessen zu erproben. In Gruppen von bis zu 30 Studierenden gründen sie ein fiktives Unternehmen der Automobilbranche mit verschiedenen Abteilungen (u. a. Marketing/Vertrieb, Konstruktion & Design), entwickeln Zielsysteme sowie Unternehmensstrategien, definieren und koordinieren Kommunikationswege und konstruieren ein innovatives Automobil unter der Anleitung von 40 erfahrenen und aufwendig geschulten Coachs. Das Arbeiten in Teams und die Kommunikation zwischen den Abteilungen zeigt den Studierenden binnen kürzester Zeit authentisch die Relevanz der Vorlesung (bzw. der vermittelten Inhalte) sowie den Bezug zur Arbeitswelt und schafft gleichzeitig die Sensibilisierung für die Notwendigkeit strukturierter Kommunikation und Organisationsprozesse.

### *3.6 Online Prüfungssystem (OPS)*

Um die Prüfung von über 1000 Studierenden ressourceneffizient und gleichzeitig lernzielorientiert zu gestalten, erfolgt die Abnahme des Prüfungsnachweises (insgesamt ca. sechs Kohorten à 120 min) über ein digitales Online Prüfungssystem. Die von den Lehrinhalten abgeleiteten Klausurfragen werden in unterschiedlichen Taxonomiestufen (Schwierigkeitsstufen) geclustert und über ein randomisiertes Verfahren den Studierenden zugeteilt [13]. Dabei werden gleichermaßen Wissen abgefragt, als auch Transferleistung eingefordert. Die Aus- und Bewertung der Prüfungen erfolgt im Anschluss automatisiert und elektronisch.

## 3.7 (Interaktive) Videodokumentation

Wie bereits die Ergebnisse des Ideenwettbewerbs (siehe Teachling-Learning.EU, www.teaching-learning.eu) gezeigt haben, besteht von Studierendenseite ein großer Bedarf an digital aufbereiteten Lehrinhalten. Aus diesem Grund und durch das Redesign ermöglicht, wurde im WS 2012/2013 die komplette Vorlesung neu aufgezeichnet und sukzessive den Studierenden über das Lehr- und Lernportal der RWTH Aachen ($L^2P$) und den Institutsserver zur Verfügung gestellt.

Wie Abb. 5 zeigt, handelt es sich dabei um eine interaktive Videodokumentation. Den Lernenden wird durch die Aufbereitung der Inhalte eine gezielte Wissensrekapitulierung ermöglicht. Außerdem werden sowohl die Folien inkl. Freihandzeichnungen und Animationen als auch ein Mitschnitt der Ausführungen der Dozentin bzw. Expertinnen und Experten dargestellt. Gleichsam wird so der Grundgedanke des „Corporate Learnings“ aufgegriffen. Der bzw. die Lehrende fungiert als Vermittler oder Vermittlerin und stellt Inhalte über unterschiedliche Kanäle zur Verfügung [16]. Den Lernenden wird so ermöglicht (on Demand), für sie relevantes Wissen zu wiederholen und zu verstetigen sowie sich gezielt auf die lehrveranstaltungsabschließende Prüfung (Klausur) vorzubereiten (in Kürze stellen wir auf unserer Institutshomepage http://www.ima-zlw-ifu.rwth-aachen.de einen ausgewählten Vorlesungsvideomitschnitt exemplarisch für Interessierte zur Verfügung).

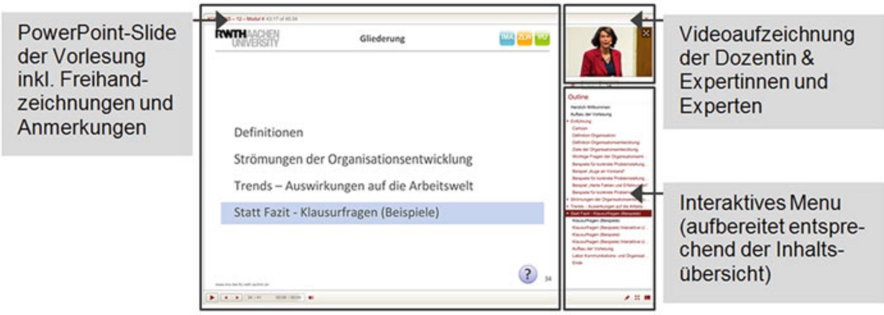


**Abb. 5** Oberfläche Videomitschnitt der Vorlesung [Eigene Darstellung]

## 3.8 Austausch- und Datenplattform

Als Reaktion auf die veränderten Einflussfaktoren (z. B. neues Nutzungsverhalten) werden den Studierenden bereits seit dem Jahr 2007 Inhalte (Präsentationen, weiterführende Literatur, Informationen zu Terminen etc.) über das Lehr- und Lernportal der RWTH Aachen „$L^2P$“ digital zur Verfügung gestellt. Darüber hinaus haben diese die Möglichkeit, sich in einem Diskussionsforum untereinander und mit den Lehrenden sowie Betreuerinnen und Betreuern auszutauschen. Diese mediale, den Lern- und Lehrprozess unterstützende Plattform ist passwortgeschützt und ausschließlich den für die Veranstaltung angemeldeten Studierenden vorbehalten. Andere können Vorlesungsinformationen, Impressionen sowie Ansprechpartner und -partnerinnen über die Institutshomepage einsehen.

## 4 Ausblick

Im Zuge des Redesigns der Vorlesung „Kommunikation und Organisationsentwicklung“ wurden erstmalig eLearning Elemente wie die Nutzung des Lehr- und Lernportals ($L^2P$) zur Bereitstellung von Lernmaterialien sowie die aufbereiteten Videomitschnitte der Vorlesung integriert. Damit wurde die Vorlesung entsprechend der Bedarfe seitens der Studierenden und der zuvor dargestellten veränderten Einflussfaktoren didaktisch und methodisch angepasst. Die ersten Evaluationsergebnisse nach dem Redesign der Vorlesung zeigen, dass die Neuerungen im WS 2012/2013 einen positiven Einfluss auf die studentische Beurteilung der Lehrveranstaltung haben. Im Durschnitt verbesserte sich die Bewertung der Veranstaltung um eine halbe Note (0,5 | artih. Mittelwert). Beispielsweise wurde der Einsatz von Hilfsmitteln und Demonstrationen im Rahmen der Vorlesung mit der Note 1,7 (arith. Mittelwert, $n = 382$) bewertet (Steigerung um 0,4). Ebenso wurde ein positiver Trend in der Vermittlung der Lehrinhalte („Die Dozentin kann den Stoff verständlich erklären“) konstatiert (arith. Mittelwert von 2,4 im Vorsemester auf 2,1 im WS 2012/2013). Als Gründe hierfür werden die neu implementierten Elemente, wie der Einsatz des ARS-Systems, der digital aufbereitete Videovorlesungsmitschnitt sowie die Praxisbeiträge genannt.

Für eine kontinuierliche und bedarfsgerechte Verbesserung der Lehre besteht weiterhin Optimierungspotential der KOE-Vorlesung. Neben Überlegungen, die bislang im ersten Semester stattfindende Lehrveranstaltung zu einem späteren Zeitpunkt im Curriculum (ggf. ab dem vierten Semester) zu positionieren und dadurch eine erhöhte thematische Sensibilisierung der Studierenden zu erreichen, ist ein langfristiges Ziel, die Vorlesung nach der Methode des „just-in-time teaching“ [17] zu konzipieren und (Inhalte) aufzubereiten bzw. anzupassen. Danach werden Präsenzveranstaltungen nicht mehr primär dazu genutzt, Lehrinhalte zu vermitteln, sondern vielmehr wird angestrebt, die Studierenden in der Vorlesung zur Interaktion zu motivieren sowie Fragen zum und Probleme mit dem Lehrstoff zu diskutieren. Vor jeder Präsenzveranstaltung werden den Studierenden hierzu Aufgaben und Fragen online zur Verfügung gestellt. Lehrende können so die Ergebnisse der Studierenden vor der nächsten Vorlesung „just in time“ sehen und entsprechend ihre Vorlesung aufbauen. Mit dieser Methode erhalten Lehrende zum einen Feedback über den Wissens- und Lernstand der Studierenden, womit sie auf die Bedarfe der Studierenden eingehen können. Zum anderen werden neue, studierendenaffine Medien eingesetzt. Des Weiteren erlernen Studierende überfachliche Kompetenzen, indem sie eigenständig

Fragen formulieren sowie Aufgaben selbstorganisiert bearbeiten müssen. Die stetige Weiterentwicklung der Lehrveranstaltung „Kommunikation und Organisationsentwicklung“ dient primär dem Ziel, für große Hörerzahlen ein noch bedarfs- und zielgruppenorientierteres Lehrangebot zu schaffen.

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# Simulation-based Learning for Conveying Soft-Skills to XL-Classes

**Daniela Janßen, Sarah Valter, Esther Borowski, René Vossen and Sabina Jeschke**

**Abstract** Soft skills have become more important in higher education in order to prepare students for employability in later career. In XL-Classes, the theoretical conveyance of soft skills to students presents a special challenge. One approach for the application of theoretically imparted knowledge in practice is the concept of simulation-based learning. Simulations have been used for a long time in a variety of disciplines, particularly in high-risk areas such as medicine, aviation and space industries, using virtual environments to prepare professionals for real life situations.

The term 'simulation-based learning' is particularly used in medical education. Approaches of simulation-based learning are increasingly used by other disciplines in the context of higher education and the education of students. Based on a definition of the term 'simulation-based learning' a concept to convey soft skills in higher education courses is developed. A practical implementation of the concept is demonstrated in the paper by using it in the XL-Class "Communication and Organizational Development" for students in the bachelor programme Mechanical Engineering at RWTH Aachen University. Here, the foundation of an enterprise in the automotive industry is simulated within 1.5 days. Key skills such as team building, time management and project management are applied, experienced and trained in the simulation. Overall, 600 students pass an organizational development process in which they establish a fictional automotive company with various departments, develop target systems as well as business strategies and construct an innovative car prototype. The basic knowledge for the realization of this task is mediated via microteaching units. Therefore the developed concept transfers soft skills knowledge to students by experiencing and training them in a simulated environment.

**Keywords** Simulation-Based Learning · XL-Class · Higher Education · Soft Skills

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## 1 Introduction

In order to promote students' employability in later career, soft skills have become more important in higher education. The transfer of soft skills especially within engineering degree programs is indispensable (VDI Wissensforum GmbH. 2008. VDI Ingenieurstudie Deutschland. In: VDI Wissensforum IwB GmbH, Heft 03. 2008). Professional and certified knowledge is not the only required output of higher education, soft skills like method-, self-, organizational- and social competences are also expected from graduating students nowadays [1]. As a consequence, the higher education system has to face this challenge. The already emerging change in the design of teaching focuses on 'learning outcomes', the students' learning results and the way of achieving these results. The more student-centered and involvement-oriented design of teaching, the so called 'shift from teaching to learning' [2], is preferred over 'content-oriented' approaches. This is a major challenge for large-audience classes, the so-called 'XL-Classes', especially when soft skills have to be learned and applied in practice. In this case, classical teaching no longer fulfills the learning outcomes, as the application of theoretically imparted knowledge falls short to convey any practical relevance for future professional life. One approach for the application of theoretically imparted knowledge in practice is the concept of simulation-based learning (SBL). Simulations in general have been used for a long time in a variety of disciplines, particularly in high-risk areas such as aviation, space industries and medicine, using virtual environments to prepare professionals for real life situations [3]. Their application in medical education is described below resulting in a particular definition of the term 'simulation-based learning' and in the development of a concept for university education, using the example of a laboratory training, called 'KOE-Labor', at the Center for Learning and Knowledge Management (ZLW) at RWTH Aachen University.

## 2 A Definition of Simulation-Based Learning

The term 'simulation-based learning' is particularly used in the context of medical education and can be outlined in its use in this area. The transfer of practical skills, as the most common learning objective [4], has become an important part of medical education. SBL emerges as an appropriate teaching approach for practical and soft skills training in medical education, since research in medical education shows that the development of communication skills should not be separated from the curriculum, as it is only effective in combination with clinical knowledge [5]. SBL offers a practical and helpful tool for deepening medical students' knowledge, skills and attitudes, while protecting patients from incorrect diagnosis or treatment [6]. It also addresses the communication competency in doctor-patient-interaction, which is a crucial soft skill for a clear imparting of diagnosis to patients and relatives.

Abdulmohsen [3] defines simulation as a generic term that refers to an artificial representation of a real world process to achieve educational goals through experimental learning: "Experiential learning . . . is an active learning process during which the learner constructs knowledge by linking new information and new experiences with previous knowledge and understanding" [3, p. 36]. Simulations in general are considered as situations, in which a certain set of conditions is artificially generated in order to create real-life experiences [3]. Concluding "simulation based medical education can be defined as any educational activity that utilizes simulation aides to replicate clinical scenarios" [3, p. 36]. Regarding the implementation of SBL in university didactic, the following definition is derived: SBL is a didactic approach for the active training of practical skills in a constructed situation. The active learning process creates experience-based learning outcomes, which prepare the learners specifically for their future performance in real situations in a professional context.

## 3 A Concept of Simulation-Based Learning in Higher Education

The outlined approaches of SBL in medical education can be transferred to other disciplines in higher education. Based on the definition of SBL stated above, a didactical concept for the transfer of soft skills in higher education is derived.

The didactical concept is developed for its use in an environment close to reality with face to face-situations. Initial point of the simulation is a complex problem or an overall task, which is structured in separate stages and embedded in a realistic background story of a professional context. A class of students, which is divided in subgroups, experiences a realistic situation in time lapse. The students act as agents in the simulation and are challenged to solve problems in their subgroup in order to prevail against the competition. To solve tasks, students must activate and apply theoretical knowledge from the lecture. The separate stages should be consecutively structured, so that students have to repetitively apply skills and competences acquired in the simulation to solve the problem successfully. Therefore a continuous learning process is initiated that leads to an even higher learning success.

The different simulation stages and problem elements stimulate communication and team processes, which promote soft skills like communication-, teamwork- and problem-solving-skills. The features professional context, team training, skill acquisition, deliberate practice and feedback, identified by McGaghie et al. [4] are the key features of simulation based learning. As an element of simulation, the team development process makes an important contribution towards the 'learning outcomes'. The initial divided subgroups meet each other during different stages of the simulation. Through the extension of the groups at different stages, the whole class of students is united again at the end of the simulation. One key element of the team development process is the definition of each role within the team, which should be made transparent to all participants. In order to create turbulences within teams, agents are purposely substituted because by mixing up students to new and different teams, new situations evolve and the ability to work in a team is fostered. Like in the real world, the subgroups receive predefined and standardized instructions with a limited number of information and a limited time frame to carry out their task. Strategies for problem solving should be independently developed by the subgroups.

Each task stage should be followed by a period of reflecting, modeled after Kolb's Learning Cycle [7]. Therefore debriefing after a task as well as feedback, where the groups reflect upon their group performance in the last stage, plays a crucial role in the simulation [4].

Overall, coaches play a central role in SBL. They assess the progress, diagnose problems, provide feedback and evaluate overall results. For a successful implementation of simulations, coaches need to undergo intensive training. To experience the learning process at firsthand, coaches receive a detailed speeded up training on learning contents and objectives in a separate training for them.

Simulation-based education provides opportunities to train soft skills in a risk-free environment by giving and receiving direct feedback and learning from mistakes [4]. Traditional teaching, such as frontal lectures, should not be replaced, but rather complemented by SBL in order to integrate soft skills and their practical application in teaching.

## 4 The Practical Example 'KOE Labor'

The concept of SBL as stated above has been transferred to other disciplines in higher education by the ZLW. This best practice example of SBL in higher education takes place in the education of mechanical engineers at RWTH Aachen University. Within their first semester, students attend the compulsory lecture 'communication and organizational development' (KOE) for engineers. This lecture is mainly designed as a traditional classroom lecture with almost 1200 students. As mentioned above, the practical application of soft skills is a challenge for XL-Classes. Therefore, in addition to the lecture, a simulation-based laboratory tutorial of 1.5 days for small groups of about 35 students is implemented, where they practice the application of the lecture content 'communication and organizational processes'. This laboratory format is based on a simulated company start-up in the automotive industry in face-to-face situations with other students. In the scenario of this competition organized by the chamber of commerce and industry (CCI), 600 students per date go through a process of organizational development by founding a fictitious company with various departments, developing target systems as well as business strategies and constructing a prototype of an innovative automobile. The learning environment is characterized by a fictitious but nonetheless realistic situation and certain challenging tasks, like real-world problems for example communicational challenges, new and unexpected information and demands, limited information. The basic knowledge for the realization of tasks is mediated via microteaching units [8, Fig. 1].

On the first day of the laboratory, lecture content is repeated and deepened by the practical application. The students have the task to develop an innovative concept for a one-day introductory tour for first semester students, which they have to present at the end of the day. Collaboration in teams fosters their teamwork ability, the ability to co-ordinate tasks, to delegate assignments, to set goals and develop their presentation skills through the presentation of the concept in front of the other students.


**Fig. 1** KOE participants

On the second day, the students found their own company in three stages: company development; internal set up of departments and coordination with other departments; planning and implementation of an automobile prototype which serves as a discipline specific content. In the first phase, the students develop a general and organizational concept for their company. This includes a model, an organizational structure and identity as well as the process of communication. The departments design, construction, body construction and marketing departments are established in the process. In the second phase, the previously founded departments define their tasks and objectives in order to be able to coordinate communication channels and the cooperation of the separate departments. The third and last stage of the company foundation is about planning and constructing the prototype. The planning phase is essential for the future construction of the prototype. In this stage, the plan for the construction is specified, as the students develop project-, time- and action-plans which determine who performs which task when and how the departments should communicate and cooperate with each other. The subsequent constructing phase shows how effective the previous phases were. During this phase, they develop a marketing concept that is presented together with the prototype afterwards in front of the competitors (Fig. 2).

**Fig. 2** KOE students during the construction phase

At the end of the simulation, all prototypes are presented at the market place and are judged according to the criteria of technical innovation - regarding engine, equipment, sustainability, quality of workmanship and design - as well as the presentation according to the criteria of professionalism and creativity and the communication and organizational processes. These processes are of an essential importance for the detailed phases of the business formation. Communication skills, team building, time and project management, decision making and organizational skills are promoted. During the simulation, the students are supported by specially trained coaches in an advisory role, who bring the students out of the simulation into a meta-level reflecting the process in terms of communicative, collaborative and organizational aspects. Supported by the respective coach, central learnings are recorded and visualized on posters for future stages. During the reflection process the coaches provide professional feedback concerning the performance of the group in the last stage. This feedback provides specific recommendations of actions for the next phases and reflects the self-perception of the group through the extrinsic perception of the coach. Apart from the direct effect of the feedback the coach indirectly influences the students as a role model by giving them professional feedback according to predefined rules. This also fosters a learning effect on students' feedback ability. Reflection and feedback of ongoing group processes foster a gradual competence gain from stage to stage. The simulation sensitizes the students' necessity of structured communicational and organizational processes. The relevance of these processes in the real working environment and the relevance of the lecture content become apparent for the students. Even the processes become shapeable by the individual experience in small groups. The developed concept transfers soft skills knowledge and practical application to the students through experience and trains them in a simulated environment. Based on experience and the run through business simulation, awareness for relevance of soft skills in daily routine is fostered.

## 5 Outlook

The concept of SBL is especially suited for the integration of practical competencies and soft skills in lectures in the field of higher education. In the case of lectures with large-audience, SBL serves as a concept to impart and apply practical skills. The evaluations of the KOE-Labor since 2007 show that the integration of SBL in the first semester is to be regarded as critical. To be able to draw on basic knowledge and existing experiences, fundamental course contents as well as practical knowledge from traineeships and scientific activities must be existent. Therefore, while designing a lecture based on SBL, the integration in the curriculum should be considered to be imbedded later on in the curriculum, when students have completed the orientation period. Simulation-based education should be scheduled and executed throughout the curriculum in order to increase the practical relevance sustainably, and combined with other educational methods such as problem-based learning, practice modules, laboratory work and others [4]. For the purpose of constructive alignments, more attention should be paid to the interconnection with the lecture as well as with the examinations at the end of the semester. Also an assessment concept, which examines the soft skills directly during the simulation, should be developed.

According to the subject, increasing the fidelity of the settings is reasonable. For example this can be done in virtual or remote labs. Virtual and remote experiments allow experiments that are not possible in reality due to increased risks and financial reasons. Furthermore, through the experimental approach to abstract topics experiments provide access to "hands-on" experience.

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# An Introductory Mathematics Computer Course as a Supplement to a Mathematical Bridge Course

**Sabina Jeschke, Olivier Pfeiffer, Omar Musa Hasan and Erhard Zorn**

**Abstract** At the beginning of their studies the majority of freshmen are overcharged in the transition from high school to academic education. The biggest continual problems appear in mathematics for engineering students or natural scientists. This is based on the high degree of abstraction and on the fact that the mathematical education takes place at the beginning of their 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 of Technische Universität Berlin offers a four-week introductory course to mathematics before the beginning of each semester. The course is addressed particularly to freshmen of engineering, natural sciences and mathematics. Additionally, a so-called mathematics computer course is offered with capacity 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, how to employ a computer algebra system (Maple) and they obtain an introduction to the scientific text processing system LaTeX. We investigated if the mathematics bridge course and the mathematics computer course lead to a better academic performance by the students in their later courses.

**Keywords** 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 in engineering and natural sciences the biggest problems in transition from high school to university appear in their mathematics courses. Moreover, as opposed to high school, success at the university requires self-organized learning to manage the unusually high density of the syllabus: For example, 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. Furthermore, because working in teams is typical for their future professional life, students need to have already been trained to work in teams at the university. Therefore, at German universities it is not unusual to hand in assignments by teams of two or three students.

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 voluntary courses and they are intended as a repetition of the mathematics that (should) have been learned at high school [1–3]. Some courses are designed to give the freshmen the opportunity to discover their strength and weakness [4]. Additionally, there are courses where students have the opportunity to take the mathematics of the first semester before they enroll at the university [5].

## 2 Mathematics Bridge Course

In order to facilitate the transition from high school to university the Department of Mathematics of our university 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 200–300 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 and assignments are offered but cannot be graded.

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

**Fig. 1** Lecture hall during the mathematics bridge course

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
- 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 1/3 of the freshmen students in engineering, natural sciences and mathematics 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 [6]. This course was developed at the Royal Institute of Technology (KTH, Stockholm) and it is offered to all freshmen at Swedish universities. This course was translated to German (and English) 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 [7]. The online bridge course - as well as the face-to-face bridge course - starts before the official enrollment at the university. Therefore, users only have to register at the website, but there is no proof of future enrollment required.

## 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 all freshmen, in particular students in engineering, natural sciences and mathematics. This is also a voluntary course which is attended by approximately 1/6 of all freshmen in these fields. Most of them (79 %, see Fig. 3) at least also attend the mathematics bridge 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.

The mathematics computer course has been 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, natural sciences and mathematics majors and there are only approximately 27 % 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 civil service is not obligatory any more, but the female/male ratio of the participants has not changed. The reasons are not obvious and have to be investigated in the future.

**Fig. 2** Students working in the Unix Pool

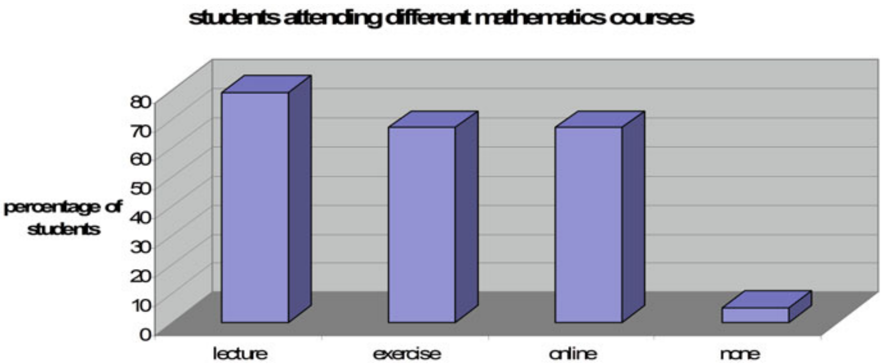


**Fig. 3** Percentage of students attending different mathematics preparatroy courses (winter semester 2011/12, multiple answers permitted)

In the two-week mathematics computer course the participants learn how to handle the Linux operating system [8], they learn the employment of the computer algebra system Maple [9–11] and they obtain an introduction to the scientific text processing system LaTeX [12–15]. Mathematics as a universal tool for 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.

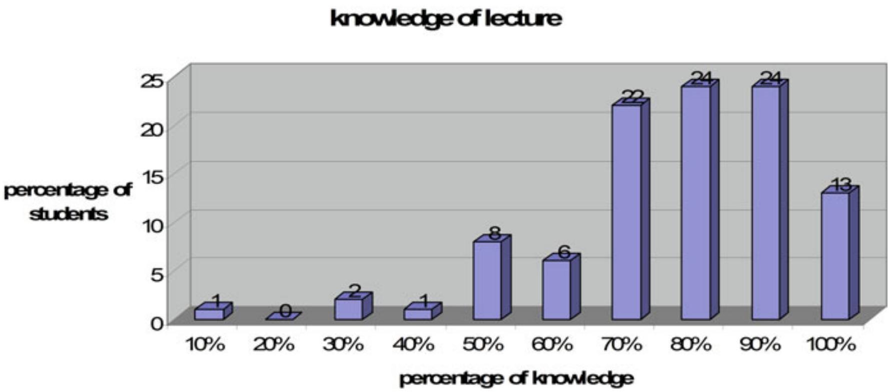


**Fig. 4** Knowledge of the topics of the mathematical bridge course (winter semester 2011/12, esitmated by students)

The main reasons for the freshmen to participate in the mathematics computer course are as follows (winter semester 2011/12, multiple answers permitted):

- I want to repeat more mathematics. (50 %)
- I want to learn new topics useful for university. (38 %)
- My high school diploma dates back some time. (37 %)
- I doubt my mathematical skills. (16 %)
- This course is known to be helpful. (14 %)

On the other hand, 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 uses the Linux operating system. Therefore, we integrated a short introduction into Linux 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 a computer algebra system (Maple) instead of standard numerical software (e. g. MATLAB [16]) 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 open source software like Maxima [17]. 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. The graphical interface and the advanced work sheet mode of Maple is the reason why we decided

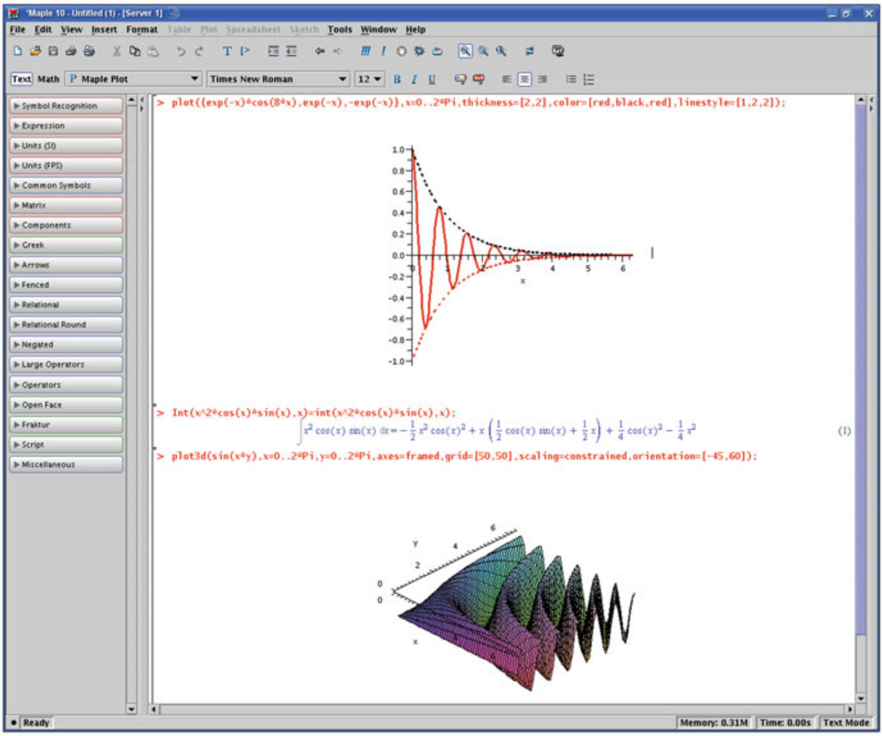

Fig. 5 Screenshot of graphical interface of Maple

not to use MATLAB which also does symbolic mathematics to some extent. Last but not least, we prefer Maple instead of the other leading commercial computer algebra system Mathematica [18] for reasons of price policy. Even though we use commercial software, we recommend to the students installing open source software like Maxima on their own computer.

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 teaching is unfamiliar. Therefore, an emphasis of the course lies in conveying the employment of the computer as a tool for research.

**Table 1** Average grades of MCC students and other students for selected courses

| Course | Average grades of students in MCC | Average grades of other students |
|---|---|---|
| Linear Algebra | 2.53 | 2.92 |
| Calculus I | 2.71 | 3.14 |
| Calculus II | 2.55 | 2.95 |
| Mechanics I/Statics | 2.82 | 3.02 |

## 4 Evaluation

The mathematical bridge course and the mathematics computer course are both popular courses that are attended by several hundred freshmen each year. The mathematical bridge course is offered as an opportunity to repeat high school mathematics and to bridge the gap between the freshmen's mathematical skills and the high school mathematics needed at the university. Additionally, the mathematical computer course introduces the computer as a tool for learning and research in mathematics. Students are encouraged to think more on mathematical modeling of problems and to use software for routine calculations.

Even though both are voluntary courses and the participants are investing a lot of time it is an interesting question if there is evidence that both courses help to improve the students' performance in later academic courses. This is a difficult question for several reasons: As mentioned above, the courses are held before the students are enrolled. Therefore, there is no access restriction to the lectures/exercises of the face-to-face bridge course and the online bridge course. There are also no assignments handed in that could be used to get data of participants of the face-to-face bridge course. The data of the online bridge course can be used to analyze how the participants perform during this course. But for data privacy protection reasons it is very difficult to identify freshmen attending the online bridge course with students in later university courses.

Fortunately, since winter semester 2010/11 in the mathematical computer course we are using the moodle [19] course management system of our university to distribute course material like Maple work sheets. The mathematical computer course starts after the face-to-face bridge course. At the beginning most of the students - or at least one member of two students who are working as a team - already have their access data to use the campus network including moodle. Therefore, we have been able to compare the performance of students who attended the mathematical computer course (MCC) with students who did not take this course.

We selected three mathematics courses and an engineering course that are attended by most engineering students. The students have to take final written exams that are graded on a scale from 1.0 (excellent) to 4.0 (sufficient) and 5.0 (failed). The increments are 0.3 and 0.7 (1.0 and 1.3, excellent; 1.7, 2.0 and 2.3, very good, and so on). The following table shows the average grades of the students who attended the mathematics computer course (identified as mentioned above) and the average grades of all other students in these courses (Table 1).

The results show that students participating in the mathematical computer course get significantly better grades in these mathematics courses (0.39 to 0.43) and in Mechanics I/Statics (0.20). As most of the students in the mathematical computer course also attend the mathematics bridge course this gives a hint that there is a correlation between these bridge courses and the performance in later academic courses. We could only identify approximately half of the students in the mathematical computer course because the students worked together in teams of two students and they therefore only used one computer account to access the course material. Thus, statistically there should be a bigger difference of the average grades between these two groups if all participants would be taken into account.

One should be careful to interpret these results. One should at least take into account that freshmen who are spending four weeks to pass voluntary mathematics courses might be more motivated than other students. These results have to be thoroughly analyzed to investigate if at least a part of these results is based on students' motivation.

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# On-professional Competence in Engineering Education for XL-Classes

**Stefan Schröder, Daniela Janßen, Ingo Leisten, René Vossen and Ingrid Isenhardt**

**Abstract** Far reaching changes in university higher education have taken place in the last ten years. Different factors, e. g. necessity of on-professional competences in engineering education, rising or vast student numbers and new technical possibilities, have influenced the academic teaching and learning process. Therefore interdependence between requirements and didactical-educational possibilities is given. Because of changed circumstances an adaption of teaching methods and concepts is required. At the same time Bologna arrogates students to be placed in the centre of the teaching and learning process and claims on-professional competences for today's students. Especially for XL-Classes this is a specific challenge. One of the questions ensuing is how to increase learning success by the use of specific didactical methods? With a research approach connecting different proven didactical concepts and considering the previously shown conditions, the concept of the lecture "communication and organizational development" (KOE) at RWTH Aachen University has been redesigned. This lecture, organized by the Institute Cluster IMA/ZLW & IfU at RWTH Aachen University, is mainly frequented by up to nearly 1300 students of the faculty of mechanical engineering and inherent part of the bachelor-curriculum. The following practical example prospects the multi-angulation of didactical concepts and shows up innovative educational teaching.

**Keywords** Engineering Education · Audience Response System · On-professional Competences · Best-Practice

## 1 Introduction

Innovative teaching techniques and concepts have been developed in the last years against the background of different factors of influence in the teaching process of higher education. This paper presents a best-practice example, which implements and combines different didactical concepts in higher education. The combination of

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different concepts is necessary as set out in Sect. 2 – Challenges in context of higher education.

In the course of years multifarious didactical concepts have been created. Research reveals different human learning types and success, depending on learning environments [1]. It follows and carved out that integration of learning methods and styles is essential.

Bologna claims the design of student-centered education formats and conveyance of on-professional competences [2], which is challenging especially in large-audience courses, the so-called "XL-Classes". On-professional competences are understood as competences which enable students to deal with their theoretical specialized knowledge and prepare them for working life. These competences comprise e. g. methodological-, social-, self-reflecting- and media-skills.

By means of the lecture "communication and organizational development", organized by the Center for Learning and Knowledge Management (ZLW) of the RWTH Aachen University, it is highlighted, how and against which backdrop the lecture was subjected to a whole redesign to cope with the changed influence-factors, technical possibilities and student-requirements. This redesign is mentioned in Sect. 3 – Redesign of the lecture 'KOE'.

## 2 Challenges in Context of Higher-Education

During the last decade far reaching changes in higher education teaching took place. Different factors have influenced the design of higher education, for example conveying on-professional competences in higher education, the high number of students at German universities and (new) technical opportunities. These most important challenging factors will be elaborated in the following.

### *2.1 The Challenge 'XL Classes'*

In Germany, many Universities face the challenge of a vast number of students each semester, especially in engineering education degrees at RWTH Aachen University [3]. This challenge is tightened by the reduction of school time by one year due to a change in German educational policy. In addition to that the demand for engineers in Germany is growing [4]. More than ten years after implementing the Bologna Declaration, the higher education system in Germany has changed significantly [2]. Since then students and their learning process represent the core of the teaching and learning process. This change, also known as a 'shift from teaching to learning' [5], is a more student-centered and involvement-oriented design of teaching. 'It is characterized by innovative methods of teaching which aim to promote learning in communication with teachers and other learners and which take students seriously as active participants in their own learning, fostering transferable skills such as problem-solving, critical thinking and reflective thinking' [6]. Instead of being 'content-oriented', which means focusing on the transmission of content, the design of teaching now focuses on 'learning outcomes', hence the students' learning results and the way of achieving these results. This is, however, a major challenge to lecturers of XL-Classes, as they predominantly focus on the transmission of content due to their difficulties of involving a large number of students at the same time. Therefore the question arises how a lecture can be student-oriented in XL-Classes.

## *2.2 Conveyance and Promotion of On-professional Competences*

Due to the huge number of students attending lectures- XL-Classes have the problem of a content-oriented focus. Therefore the conveyance of on-professional competences to students in XL-Classes is often in a theoretical way. Indeed the transmission of on-professional competences plays an important role in higher education in general and particularly in engineering degree programs [7]. Not only professional knowledge is required to be the output of higher education, but also soft skills like method-, self-, organizational - and social competences are expected from today's students [8].

Against this background the required competences are considered at the redesign. From its multidisciplinary and holistic approach, the ZLW aims at designing and conducting lectures also including the transmission of on-professional competences. Thereby the ZLW tries to accomplish one major goal of the Bologna Process, which is "to create a European space for higher education in order to enhance the employability [. . .]" [2]. Students should be educated in a way which makes them available for the employment market in a fast, efficient and adequately educated manner [9]. This means students should be enabled to convert learned knowledge in higher education in later working life [10].

## *2.3 Combination of Didactical Concepts*

Didactical concepts are the tools of today's lecturers. Those concepts and methods are combinable and applicable in various ways. Due to the didactical diversity of methods a student-centered alignment of lectures is possible. The students learning process is further supported through didactical multi-angulation [11].

Additionally, the students obtain skills in dealing with various methods through methodical diversity (e. g. with presentation techniques). Böss-Ostendorf and Senft confirm that useful methodical diversity is a factor of success for university education, because of the multiplicity access to teaching content [12]. The reasons for integration and combination of different didactical concepts are mentioned by Flechsig [1]:

- Various learning styles and types of students with different learning success
- Diversity of study motivation and interest
- Variety of competences and fields of knowledge
- Variety of context in which learning is placed

| Didactical multi-angulation of the lecture 'KOE' | |
|---|---|
| A | Theoretical inputs and lecture modules |
| B | Practice oriented theoretical inputs through expert-lectures with professional practice |
| C | Interaction in XL-Classes through Audience Response Systems (ARS) |
| D | Learning on demand through medial preparation |
| E | Teaching and learning online portal/platform |
| F | Simulation based learning through organizational simulation |
| G | Online examination system |

**Fig. 1** Didactical elements 'KOE' lecture at RWTH Aachen University

Any didactical method aims at enforcing learning and knowledge permanently [13]. As a result a sensible combination of didactical methods and concepts to increase learning-success for students is necessary. As a consequence concepts, explained in the following, have been integrated in the lecture 'KOE'.

## 3 Redesign of the Lecture 'KOE'

The compulsory lecture "communication and organization development" (KOE) is held every winter term. Almost 1300 students, mostly engineering students, participate in this weekly lecture. In addition a laboratory session takes place, in which students experience a simulated company situation in an authentic environment [14]. Based on the changed influence factors, which are mentioned before, and with the premise to maximize learning success and also among the maxim of sustainable teaching of practice-oriented and on-professional contents, the lecture is continuously refined and was subject to a complete redesign in the winter term 2012/2013. Existing elements were further developed and new didactic elements were implemented. The lecture's elements (shown in Fig. 1) will be explained in the following.

### *3.1 Theory Input and Lecture Modules*

The lecture consists of 12 modules, including the basics of communication and organization development, learning- and knowledge management concepts and intercultural aspects of global work division management as well as system-theoretical

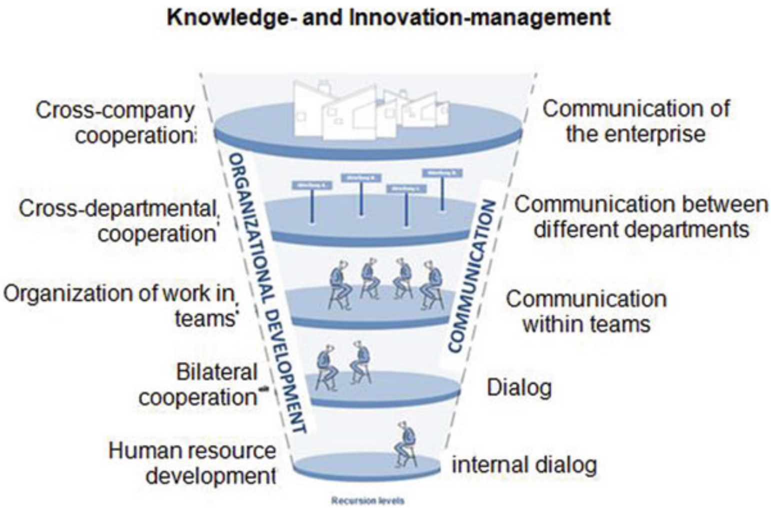


**Fig. 2** 'KOE' funnel/recursion-layers [14]

approaches and practical inputs by experts from industry. The whole concept of teaching follows a linear structure. Practical lectures tie in with earlier taught theoretical contents. Thus an ideal transfer from theory to praxis is established. At the end of every module contents are reflected and summed up. For this purpose the 'KOE funnel' is applied (Fig. 2). Both the systemic view and the different levels of a company are included. Thereby communication and organization are regarded as the most important requirements for the development of interaction between humans, technique and organization on the different organizational levels, for example within departments or project teams.

## 3.2 *Expert Lectures*

As already stated the lectures redesign aims for an increasing relation to practice applications and does not only focus on technical expertise. Additionally it also aims at increasing the ability of understanding the complexity of working life. The inclusion of on-professional competences in studies is not only an issue since the Bologna reform [15]. Furthermore it is important to connect the studies with professional practice, not only from the student's perspective, but also from the perspective of company representatives [16]. For this reason, it is more important to connect teaching with practical insights [15]. Based on this, guest speakers with professional industrial background give an insight into their companies and working experiences (e. g. Vodafone Group, Capgemini, p3 group, inside group of companies). For example: Lecture contents are the experiences in handling international projects as well as interdisciplinary challenges. The experts as well as the lecturer try to establish the connection between already taught theoretically contents and the meaning of communication and organization development in daily processes. In this way theories are linked to praxis and relevance is outlined. In order to solve the area of conflict between the teaching of basic sciences and practical teaching at the expense of theoretical essentials [17] the distribution of proper contents and basics is kept reasonable.

### *3.3 Interactivity through the Application of "Audience Response Systems"*

As outlined by Prensky, that "our students have changed radically" and that "today's students are no longer the people our educational system was designed to teach" [18] (new) technologies e. g. in the form of 'Audience Response Systems' (ARS) may improve the learning outcomes of students [19]. Due to the application of an ARS, students are further involved in the education process.

The ARS is a valuable didactical element as already mentioned by Brinker/Schumacher in 2009 [20]. Capabilities to participate in a lecture are quite diverse for students, which means that they can choose particular contents, recap their knowledge, interpret, reflect and prepare for examinations. Taxonomies of learning goals, like knowledge, understanding, application and analyzing [21, 22] are addressed holistically by the use of knowledge and comprehension checks. As a result problem-solving skills can be improved. The barriers for participation are marginal. Only an end device with access to the internet is required.

To satisfy the student's demands and with the objective to enable interactions between lecturer and students [23], an ARS is used since the winter term 2012/2013. The implementation of the described system demands a redesign of the lecture with special regards to the content. Questions have to be developed that allow the students to interact with the lecturer as well as with each other. This variety of questions ranges from multiple-choice questions to the inquiry of calculation results etc. [19]. Furthermore iteration-loops, to repeat misunderstood content, can be taken into account.

Figure 3 illustrates the didactical concept of an Audience Response System, which is treated in the 'KOE'. Two fields are shaded grey, as this case is not applied in the lecture. If there are less than 30 % correct answers, an explanation on the right answer is given. Provided that the content is understood ($>$ 80 % correct answers), the lecturer switches to the next topic.

Evaluations of the success of the implementation of ARS in large university lectures show that the application of this "tool" has led to e. g. higher motivation of attendance, more attention of the students during class and even higher knowledge acquisition than in conventional (non-interactive) classes [19]. If and how the new didactical implementation of the media Audience Response System influences the learning process of students in the lecture 'KOE', has to be evaluated during the next terms.

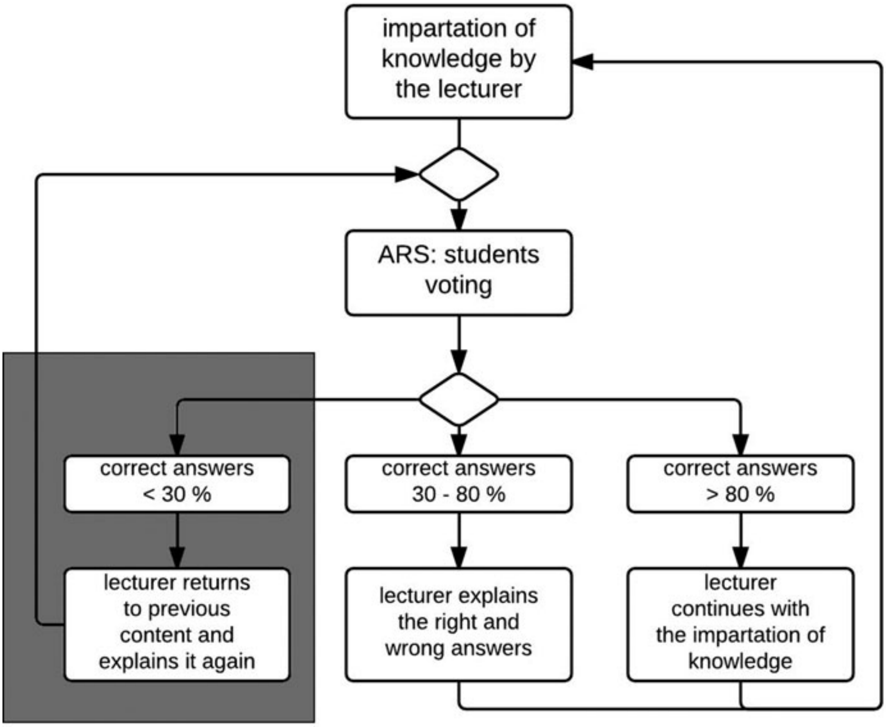


**Fig. 3** Didactical concept of using the ARS [23]

### *3.4 Video Documentation*

In the winter term 2012/2013 the whole lecture was recorded by a professional camera crew, edited and afterwards provided to the students via the online teaching and learning platform $L^2P$ of RWTH Aachen University to support the learning process in auto-didactical-phases of the students. As shown in Fig. 4 it is a matter of an interactive video documentation. For each module the chapters can be retrieved individually. Knowledge is thereby no longer appropriated as a lecturer-reserve, but accessible for students on demand. This form of making content available for students resembles the concept of learning on demand [24] and results in time saving potential for student learning [25]. Through this video documentation, the students can recapitulate content without any limit and at any time. Furthermore the presentation papers and manual sketches as well as animations and explanations of the lecturer are shown (see Fig. 4). The moderator works as a mediator and presents contents using different channels based on corporate learning. This way offers the possibility

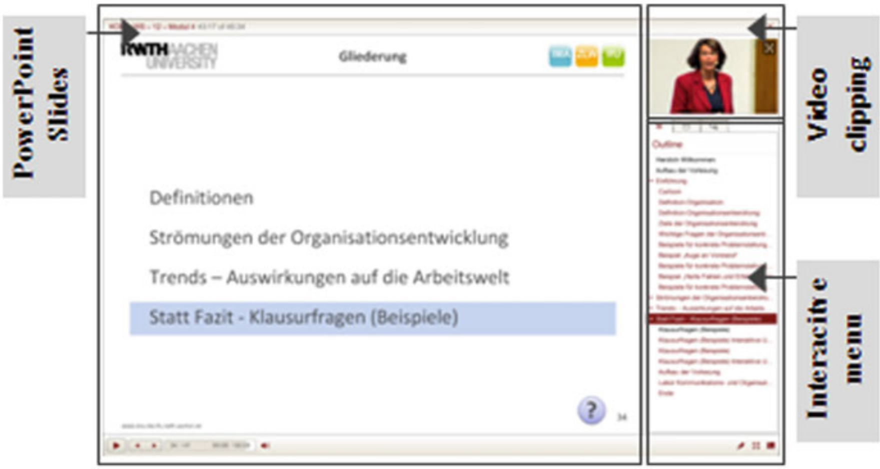


**Fig. 4** Surface of the video recording of the lecture

to review important contents and especially the preparation of exam papers could be done in a more efficient way. The result is an approach to the teaching for "individual learning", because students can decide when, where and how fast they organize their learning process [26].

### *3.5 Exchange and Dataplatforms*

As a reaction to the various influencing factors like the new technical possibilities, the teaching and learning platform $L^2P$ is used since the end of 2007. The learning platform is password secured and is just accessible for registered students.

The platform is implemented in order to provide important contents like teaching materials (e. g. lecture notes, videos and presentations of experts) and (further) literature for the students on a web based server to support time-consuming and complex teaching and learning processes [27, 28]. Additional $L^2P$ can be used to conduct surveys and simulate electronic tests.

Moreover the students have the possibility to discuss certain topics in an online forum talking to professors, mates or coaches and to obtain important clues to further arrangements. Thus discussion and dealing with lecture-content is supported and promoted. The aim is to influence the learning process to the effect that knowledge is understood by the students and can be applied. According to Palloff and Pratt the use of $L^2P$ in the lecture 'KOE' can be described as a "web-enhanced course" [29]. That implies physical as well as virtual components and thus copes with the European university-tradition in independent preparation of subject-specific content [30].

### 3.6 Laboratory Tutorial

XL-Classes are faced with the challenge of a theoretical conveyance of on-professional competences to students. During the lecture ‘KOE’ not all contents can be taught within XL-Classes [31]. Therefore parallel to the lectures a laboratory tutorial of one and a half days takes place. The laboratory tutorial is based on the concept of ‘simulation-based learning’ which is a research or training method that tries to create a realistic experience in a controlled environment [32]. According to this, simulation replaces or boosts real experiences [33] and thus offers enormous advantages in mediating knowledge long-acting [33, 34]. In groups up to 40 students a foundation of a fictitious automotive company with different branches is simulated. Target systems and various strategies are developed and communication ways are defined and coordinated. An innovative vehicle is constructed under the guidance of 40 professional coaches. The basic knowledge for the realization of this task is mediated via microteaching units. In the next step, earlier learned theoretically basics are applied practically during a company simulation in order to obtain first practical experiences in organizational communication and working processes. Students try to construct an abstract concept in a theoretical framework to finally put their findings in an active experiment. The teamwork and the communication between the different branches demonstrate the importance of the lecture as well as the relation to working life. Additional to the contents of the lecture ‘KOE’, key skills such as team building, time management and project management are applied, experienced and trained in the simulation.

### 3.7 Online Examination System

In order to examine around 1300 students efficiently and content orientated, a digital online examination system (called OPS = Online-Prüfungssystem | developed externally especially for ‘KOE’) is used and applied since 2007 [35, 36]. Examination questions are derived from the lectures contents and distinguished in different taxonomy levels (degrees of difficulty). Thereby the whole taxonomy-spectrum by Bloom 1956 [24] on a cognitive base is addressed to the students. The taxonomy levels are: knowledge, comprehension, usage, analysis, synthesis and evaluation. For the preparation of exam questions it is important to take into account, that the taxonomy levels are hierarchically arranged [37]. Hence the mediated competences for each taxonomy level must gain a specific manifestation before they can be applied in the next taxonomy level [38]. For example, without knowledge, usage of taught content (transfer capacity) is impossible [38].

Supported by a holistic handling of the mentioned difficulty degrees, the OPS enables to retrieve the student levels of awareness. With the help of the OPS knowledge and transfer capacity can be interrogated and evaluated electronically within a few minutes, so that no further staff is required.

## 4 Conclusion and Vision

Each semester a university and lecture wide evaluation is stated. First evaluation results indicate that the adaption of the lecture concept and the implementation of new technical and didactic elements have a positive impact on the student evaluation of the course, especially the use of technical aids and demonstrations as part of the lecture as well as the teaching of contents by the lecturer.The average evaluation grade rises in the order of 0.5 (arithmetic average; scale from 1 (very good) to 6 (very bad)). For example the usage of devices and demonstrations in the lecture are evaluated with 1.7 (arithmetic average). The mediation of contents also has a positive trend. Lecture records as well as implementations of ARS Systems are inter alia reasons for that.

Altogether the multi-angulation of various didactical concepts can be outlined as a success for the lecture 'KOE'. This educed concept states that students are centered in educational learning process. In a next step the transferability of the redesigned concept of the 'KOE' lecture must be elaborated. Therefore indicators for a survey will be operationalized and developed.

Based on the already mentioned scientific studies of combining various methodical concepts to increase learning-success and the first positive evaluation after the 'KOE' redesign, more innovative teaching and learning methods will be developed, taken up and implemented for this purpose in the next few years.

Furthermore there is still potential for a continuous and appropriate optimization of the lecture 'KOE'. A long-term goal is to implement additional to the existing concepts the method of 'just in time teaching' to optimize and adjust lecture contents [39].

Accordingly presence lectures are not used anymore for conveying contents, but rather to motivate the students to participate and interact in the presence lecture and to discuss questions and problems with the lecture content. Therefore questions and tasks are provided online before every presence lecture. So the lecturer can see the student's results before every lecture 'just in time' and develop the lecture according to the level of awareness. This method is used to obtain feedback related to the student knowledge. This can be used in order to precisely react to the students demands on certain contents. In addition, students get to know on-professional competences while formulating their own questions as well as working on tasks independently. The continuous development of the lecture 'communication and organizational' primarily serves the goal of creating demand-oriented and target group-oriented courses for XL-Classes.

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# Are Students Competent, Active and Constructive Partners in the Improvement of Teaching and Learning? A Text Analysis of Contributions to Idea Contests

**Katharina Schuster, Ursula Bach, Anja Richert and Sabina Jeschke**

**Abstract** In the Competence and Service Centre TeachING-LearnING.EU 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 integrate customers actively in new product developments. The main methods within this strategic instrument are idea contests and lead student workshops.

This paper presents the main results of the first three idea contests, in which 80 ideas were submitted in total. With the method of qualitative content analysis, the students' e-mails through which they submitted their ideas are investigated on a deeper level. As a result, the paper shows if students can be considered competent, active and constructive partners in terms of the improvement of teaching and learning. Moreover, it points out those areas in which the students see the biggest need for action. Since most ideas were submitted to the topics of virtual learning environments, organization/resources and digital technologies in lectures, the results of these topics are presented elaborately. The authors come to the conclusion that especially in the areas of virtual learning environments and digital technologies, students deliver a valuable input for the improvement of teaching and learning in engineering education.

**Keywords** Bologna · Engineering Education · Curriculum Development · Open Innovation in Higher Education

## 1 Introduction

Student involvement in the improvement of teaching and learning has many advantages:

- It can foster the students' general engagement in higher education by giving them a voice and strengthening their lobby.

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- It brings up ideas that have never been thought about of those who usually shape the content and the didactical principles of engineering education [1].
- It can happen on a micro level via lecture evaluation or it can be integrated in a deeper framework. [2]. Therefore it is a flexible instrument of higher education management.

In the light of the Bologna Process, the involvement of students is of high relevance. In 1999, the European Ministers of higher education among others set the goals of harmonising the European higher education area, promoting the mobility and fostering the employability of European citizens [3]. Although not mentioned yet in the Bologna declaration, the topic of student involvement came up only two years after the bologna declaration. The Prague Communiqué of 2001 states:

> 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 [4].

In 2010, when the European Higher Education Area was launched, it was stated in the Budapest-Vienna Declaration:

> 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 [5].

Within the Competence and Service Centre of Teaching and Learning in Engineering Sciences (known as TeachING-LearnING.EU) students are actively integrated in the research topics. The main goal of TeachING-LearnING.EU is to tackle the challenges brought about by the Bologna Process within the field of engineering education. Examples are to increase the employability of students, to design new teaching and learning concepts or to develop higher education didactics for lectures with large audiences. The strategic instrument for student integration is called *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.

In this paper we want to pick up on the statement of the European ministers of higher education in the Prague Communiqué. Therefore it will be analyzed on a deeper level, if the students are competent, active and constructive, in terms of the improvement of teaching and learning. The paper depicts the principle of the main method of the strategic instrument *OpenBologna*: the idea contest. It presents the results of a text analysis that has been carried out with all contributions within the first three idea contests of TeachING-LearnING.EU. The methodology of qualitative content analysis is explained on the basis of this case. The paper closes with a discussion of the results and forecast on further research questions.

## 2 OpenBologna – Student Involvement on an Operative Level

In order to give the reader a better insight which actions *OpenBologna* encompasses, the strategic instrument is described briefly:

The method of idea contests is already spread widely within different contexts. Many idea contests focus on innovative solutions for general business or engineering problems. Often they are connected to a virtual platform (e. g. www.innovationchallenge.com, www.makeitso.org). The German Initiative for Network Information (DINI) focused on the technical infrastructure of universities. So far they called out two student idea contests to the topics "Lively learning environments" and "Student networks" [6]. The idea contests in TeachING-LearnING.EU focus on topics around the improvement of teaching and learning especially in engineering education. Similar to open innovation, where customers are seen as the experts for the products they buy, students are considered to be experts for how they learn best [1]. Each semester TeachING-LearnING.EU calls out an idea contest. By awarding the best three ideas with a prize, the students are motivated through extrinsic incentives. The idea contests have always been sponsored by well-known companies (e. g. Bosch, Hilti, Philips). Moreover, the idea contests give students the chance to influence the learning environments and settings within their field of study which the university offers them. A transparent presentation of which ideas are already being implemented can be found on the website of TeachING-LearnING.EU. The competence and service centre continuously looks for partners amongst the teaching staff who want to "adopt" an idea and who want to implement it in his or her university or lecture. This aspect appeals to the intrinsic motivation and the engagement of the students.

In addition to the idea contests, TeachING-LearnING.EU uses the lead user approach. Lead users are individuals that are experiencing needs ahead of the market trend and are at the beginning of the innovation process [7]. In the case of *OpenBologna*, TeachING-LearnING.EU looks for engineering students who are interested in the development of teaching and learning. These students are identified by the idea contests or by their extracurricular activities, e. g. in student associations or as student representatives in University Boards and commissions. In workshops, the lead users or lead students as they are called within the project, develop more elaborated concepts for engineering education. The whole process of *OpenBologna* is visualized in Fig. 1. Since the procedure and the outcome of the lead student workshops are quite different from the idea contests, this paper focusses on the latter.

TeachING-LearnING.EU called three idea contests so far. The first one had the title '*Tweak your bachelor!*' and dealt with the question on how to improve teaching and learning in engineering education. The second contest was called '*Good teaching 1000+*' and covered the subject of large class management and how it can be improved. For a deeper analysis of this specific topic see Stehling et al. [8]. In the third idea contest, the students had to turn in proposals on how to give engineering education more practical relevance. The title of the third contest was '*Theoretically I can . . .*'.

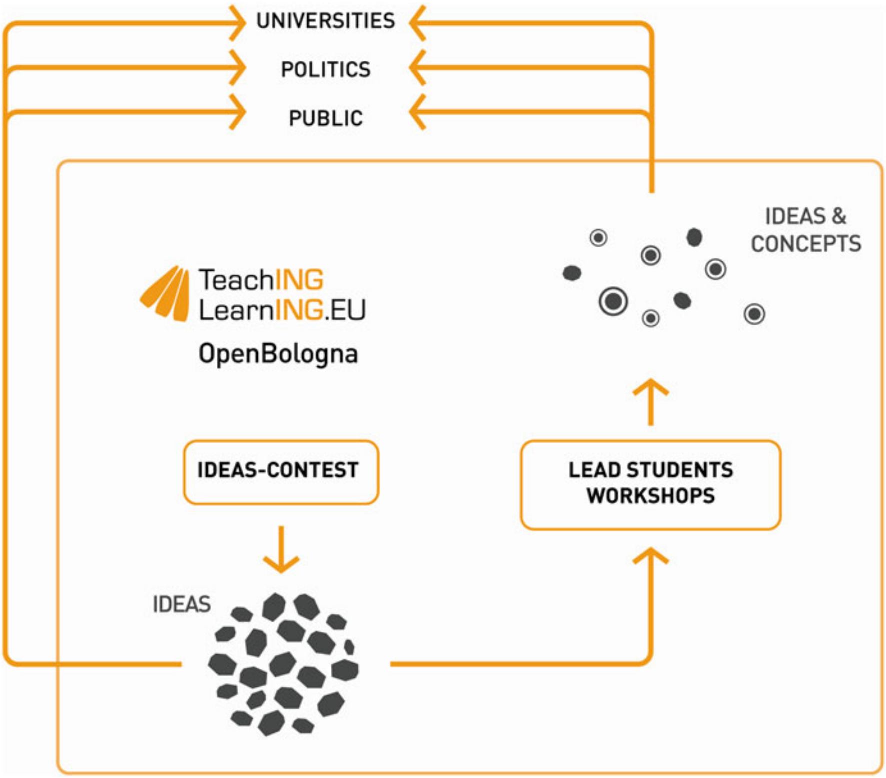


**Fig. 1** Illustration of the strategic instrument OpenBologna of TeachING-LearnING.EU

In the first three idea contests, a total number of 80 ideas had been handed in from 69 students (see Fig. 2). It has to be noted that in the third idea contest, a whole course of 34 participants submitted one idea. The ideas were judged by the criteria of quality, practicability and effectiveness. The method of choosing the winners was as follows: Each idea that had been sent in was anonymized. All the team members of TeachING-LearnING.EU in Aachen had to pick the ten best ideas.

These top ten ideas were openly discussed within the teams in Aachen, Bochum and Dortmund. Each group had to select the three best ideas. Additionally each group had to nominate students who also had one vote. Out of these six votes, the three winning ideas were identified.

The results of the analysis of the first three idea contests of TeachING-LearnING.EU help to validate the view of students as competent, active and constructive partners in the improvement of teaching and learning. They moreover help to measure the effectiveness of the strategic instrument *OpenBologna*. The research questions of this paper will be introduced within the description of the methodology used.

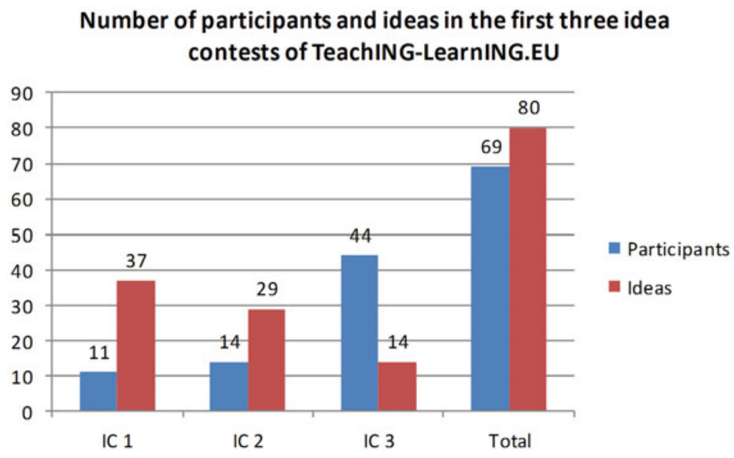


**Fig. 2** Participants and ideas in idea contests of TeachING-LearnING.EU

## 3 Methodology – Qualitative Content Analysis

The submissions of the first three idea contests were analyzed with qualitative content analysis. It is not the claim of qualitative content analysis to be representative for the population. Instead, the quality criterion of qualitative research is intersubjective traceability. In general, the method helps to understand, not to explain human behavior. Qualitative content analysis is a method to understand the single steps, that later lead to the interpretation of results [9].

Other than quantitative content analysis, which is used to put frequency distributions of certain information, qualitative content analysis examines the information for its mere content [9]. The analysis described in this paper uses the approach of Jochen Gläser and Grit Laudel [10]. For the preparation of the analysis, crude data is extracted from an already existent text. In this case, the e-mails of the participants of the ideas contests formed the text corpus. After the extraction, the data is being processed and finally evaluated.

Figure 3 illustrates the procedure of qualitative content analysis by Gläser and Laudel. In what follows its single steps will be explained. The researchers who were involved in the analysis of the data have not been involved in the jury of the idea contests. The whole analysis was done in German language; the results were translated into English.

According to the statement of the European Ministers of Higher Education in the Prague Communiqué, the variables of the text analysis are (1) the competence of the students, (2) the activeness of the students and (3) the constructiveness of the students. When the ministers put forward the view of students as competent, active and constructive partners in the Prague Communiqué in 2001, they didn't specify these characteristics any deeper. In order to continue with the analysis, the variables have to be defined. The level of activeness can be revealed by the number

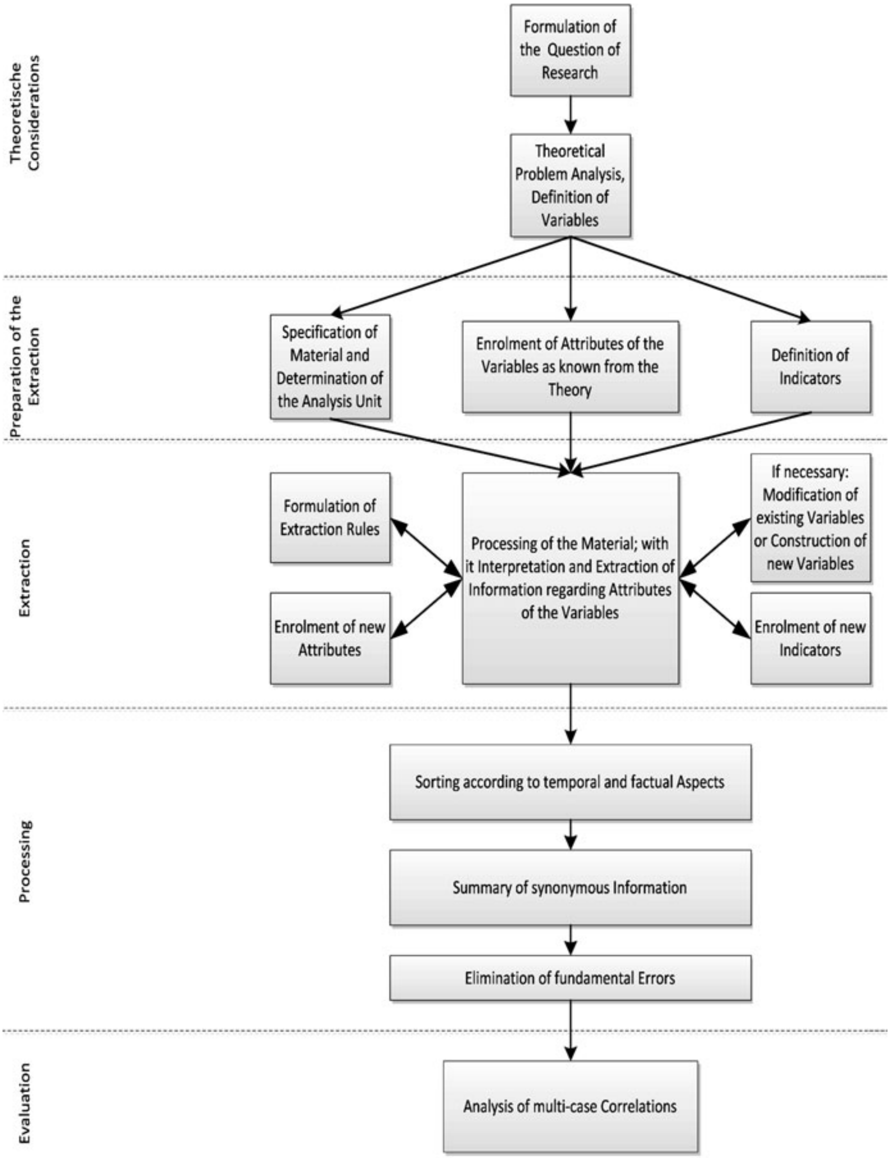


**Fig. 3** Process of the qualitative content analysis [10]

of participants and the number of submitted ideas. These numbers have already been introduced and will be discussed and put into context later on. In order to find out information about the competence and constructiveness, a definition of the terms is necessary.

The Oxford dictionary defines the term *competent* as "having ability, power, authority, skill, knowledge, etc. (to do what is needed)" [11]. In order to judge the competence of students to support the improvement of teaching and learning, we will compare the topics mostly contributed by the students to those currently discussed by the engineering education community. Moreover we will discuss the quality of exemplary ideas. This should serve as a first indicator to see if students have "what is needed" for improving teaching and learning in engineering education.

The term *constructive* is defined as "helping to construct; giving suggestions that help" [11]. For this exploratory study we will characterize students as constructive if they write about solutions for teaching and learning in a higher ratio than about problems of the current situation. After defining the variables, the corresponding three research questions are:

1. How much do the students write about solutions for teaching and learning? → information about constructiveness
2. To which topics do the students mostly submit ideas? Do they match the topics the engineering education community currently discusses? → information about competence
3. What do the students write about in these categories? → information about competence

The text corpus was generated from all e-mails which were sent in within the first three idea contests. The material was anonymized; greetings and good-bye-phrases were eliminated from the text corpus. The corpus consisted of a great amount of written data, in total 25 pages (Arial font, size 11, single-spaced, no breaks except lists of bullet points). The following analysis used the unit of paragraphs, as the other units seem too small for a proper interpretation [10, p. 204].

To distinctly assign empirical phenomena to theoretical constructs during the extraction, the attributes of the different categories as well as indicators need to be determined previously. A more distinct overview of underlying variables attributes and indicators are shown exemplarily in Table 1. In order to answer research question number 1, all parts of the text corpus have been allocated into the function-driven variables *problem*, *solution*, and *others*. In the contests students only had to turn in rough drafts of their ideas. Although the practicability of the idea is an important judging criterion, the students do not have to add an action plan for the implementation of the idea. While the descriptions of the problems refer to actual situations, the descriptions of solutions refer to hypothetical situations and their predicted consequences. Hence, the corresponding grammatical constructions served as indicators for the categories *problem* and *solution*.

In order to answer research question number 2 and 3, the text corpus has been divided again into three sub-corpora, one for each contest. All parts of the text corpora have been allocated into content-driven variables which are shown in Figs. 6, 7 and 8. Because the table with all attributes, examples and indicators is very voluminous for the variables of research questions 2 and 3, it does not appear in this paper.

After the extraction, the method for answering research question 1 was expanded by a quantitative element. The words that had been written in total in each

**Table 1** Variables, indicators and linguistic markers for research question 1

| Category | Attributes | Examples | Indicators |
|---|---|---|---|
| Problem | Description of the current situation, explanation of resulting problems for students | "The Problem is . . .", "it doesn't make sense that . . ." | Mostly use of present tense or past tense |
| Solution | Proposal of how to solve the problem, description of the solution, benefits and advantages, reference of experts to strengthen the argumentation | "It would help, if . . .", "it would make sense, if . . .", "imagine that . . .", "I suggest, that . . . ", "I know from first hand, that . . .", "my professor also likes this idea" | Mostly use of conditional clauses, use of future tense, use of imperative |
| Others | Introduction of the student, description of how student came to participate, appreciation for the initiative, metatextual elements | "I am . . .", "my name is . . .", "I study . . .", I hope it helps", "I also want to contribute . . . ", "in the following I want to describe the problems" | None specific |

variable-category were counted in order to measure the proportion. An interesting sub-question for research question 1 is if the quality of the idea correlates with the proportion of problem-related content and solution related content within the whole text. Therefore the whole analysis was repeated, but now only with the winning ideas. Since the winners of the third idea contest have not been nominated yet, only the e-mails from the first and second contest formed the text corpus.

To answer research question number 2, all the ideas that have been submitted were sorted into the content related categories. Again, the qualitative part was expanded by a quantitative element. The number of ideas in each category gives a first impression which topics are the most important from the students' point of view. To answer research question number 3, a deeper insight in the quality of the students' input was needed. For this reason the e-mails were extracted furthermore in the content-driven categories. Then, redundant information was eliminated and the content was summarized.

## 4 Results

The results of the frequency distribution of the function-driven categories are shown in Fig. 4

Since more than two-thirds of the e-mails in total focus on the solution and not the problem, the students can be characterized as constructive. However, the students whose ideas got nominated as one of the three per contest do not show any major difference in the composition of their e-mails (see Fig. 5).

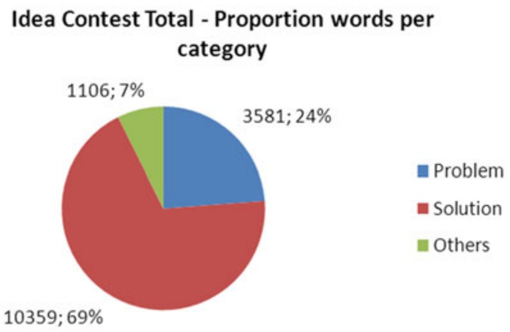


**Fig. 4** Idea contests total – proportion words per category

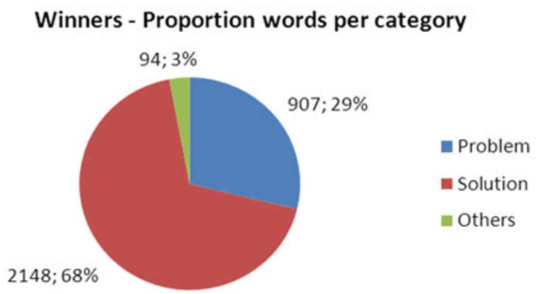


**Fig. 5** Winners – proportion words per category

As we can see in Figs. 6, 7 and 8, the students have submitted the most ideas to the topic of *virtual learning environments* (27 ideas), followed by *organization and resources* (14) and *digital technologies in lectures* (7 ideas).

The essence of the input the students gave to these topics is exemplarily presented in order to give an insight in the quality of the students' ideas and therefore their competence in terms of improving teaching and learning. The following passages only depict the students' argumentation and do not contain any judgment of the authors.

## *4.1 Virtual Learning Environments*

In this field, the students drew a vivid picture of what universities of tomorrow could be like. The more basic ideas cover data bases e. g. for internships. Many ideas deal with information management systems for learning material. The digital accessibility of scripts, documents or slide of a lecture is important to the students. They prefer a centralization of all online activities in one web portal instead of every chair using their own homepage to provide learning material. The material should be uploaded at a fixed point in time and should be ordered thematically, not chronologically or alphabetically. The students would like to have the opportunity to download many documents at once since the singular download of material is very

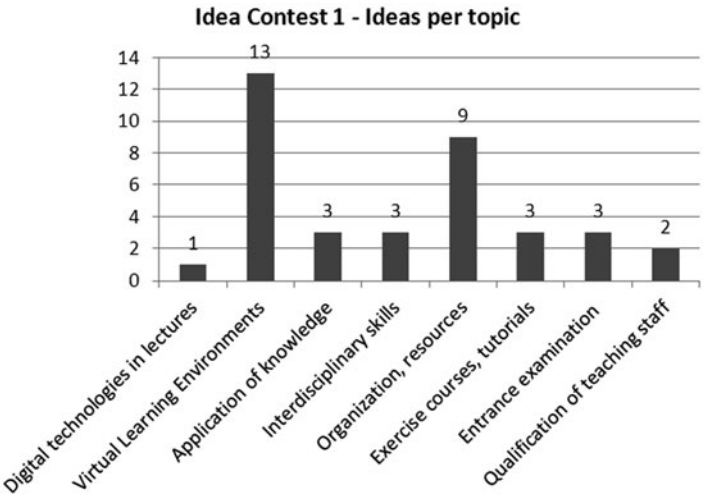


**Fig. 6** Idea contest 1 “Twerk your bachelor” – ideas per topic

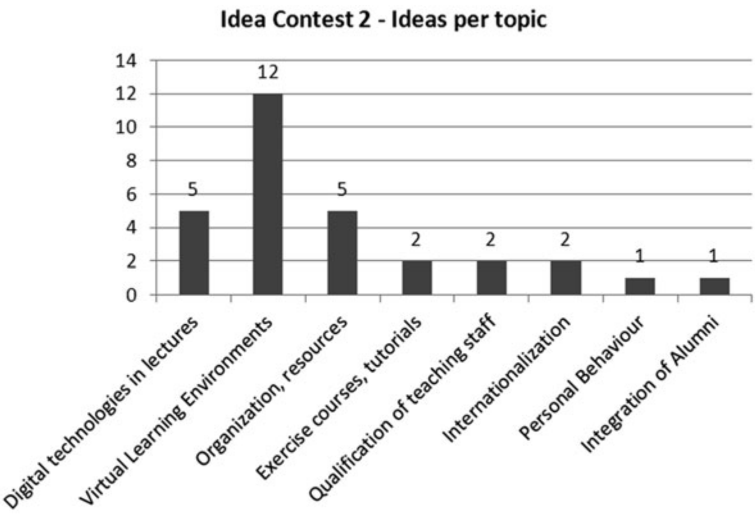


**Fig. 7** Idea contest 2 “Good Teaching 1000+” – ideas per topic

time consuming. Evaluations of lectures or professors should also be run via the web portal. The students moreover set great value on the usability and the interface of the web portal. The welcome page should be personalized and should announce lectures or extracurricular events which could be of interest for the user.

From the students’ point of view, the service side of such a web portal could have many more functions than simply providing material. One is to introduce characteristics of different learning types so the students can figure out which type they are.

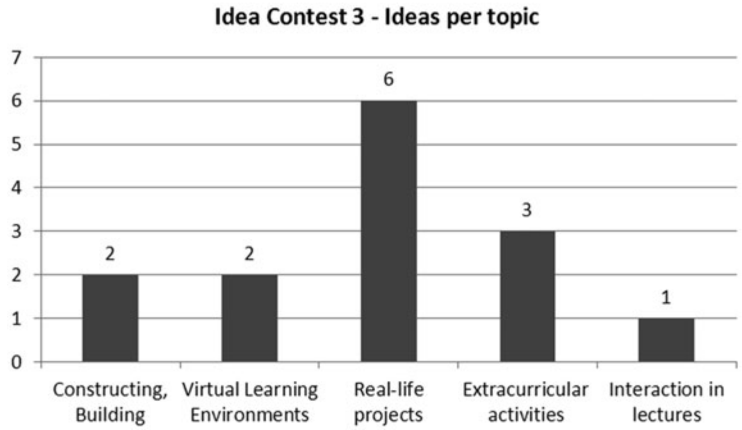


**Fig. 8** Idea contest 3 "Theoretically I can . . . " – ideas per topic

Thus, they can optimize their efficiency in learning. Another option is to introduce and to provide software that helps the students to learn and to study. Examples are a special flashcard software, e-mail programmes or simple Firefox-Add-ons. The flashcard software could also be used by teachers for the preparation of lectures by supplying the students with the central terms and their definitions they need for a specific lecture.

More interactive approaches put students in an active role who share their knowledge, help each other and creating content by themselves. On a website called "Uni-(Wiki)pedia" students could add content, connect it and communicate about it. They could also upload the material provided by their teachers in order to share it with each other. They could link video recordings, practice sheets with solutions and references. Thus, an easy and quick access to different approaches would be available. By looking at the communication threads, teachers could discover the biggest knowledge gaps. With this kind of learning portal, content of different faculties or even universities could be cross linked with no regard to institutional boundaries. Kids from school could use the website for orientation to find a degree programme that suits them.

Many ideas were about providing video recordings of lectures, especially in conjunction with large class management. Most stated advantages are the possibility to stop the video in between, to repeat parts which were difficult to understand and to reduce the number of students in the lecture hall, which results in better learning conditions (e. g. less noise and better air). The possibility to repeat the video was considered helpful especially for foreign students.

The lecture could also be streamed via internet, combined with a live chat. Students can watch the lecture from home or if they have a laptop basically from anywhere. They can then send their questions to a list which is also made public on a website. The professor's assistant can then answer the questions while the professor continues with the lecture. This helps the students to overcome their inhibition to ask a question in front of a lot of people. With a corresponding app, the students can also ask questions via their smartphones while sitting in the lecture. The virtual consultancy hour is yet another use case of the same idea. By displaying the questions and answers online, the professor or the assistant have to explain things only once. Virtual whiteboards could visualize their explanations.

The high quality of video recordings was also pointed out. Every university should have a professional filming team which produces high quality videos of crucial lectures. These videos could also be cross linked over universities on a video platform. Students can then communicate about the content and add their own material to it, just like in Uni-(Wiki)pedia. The role of video based content was also picked up in the form of a video contest for students. Professors can distribute topics of the lecture amongst the students at the beginning of the semester. During the semester, the students have to produce a video. The students can use animations, simulations, flip books or any other film technique.

The last field deals with the establishment of a social network just for students at one university. They can submit a minimum of general data such as sex, field of study and the semester they are in. An algorithm creates study groups of people in the favoured size, to the favoured study field or a specific lecture. The network provides online group work rooms but also inherits the possibility to book real existing physical rooms in order to meet face-to-face.

## *4.2 Organization and Resources*

The general suggestions in this field cover the students-to-staff-ratio. This concerns for example teaching staff, administration or course guidance. One student wished for contact persons for content-related issues, if for example the usual teaching staff cannot help with a problem that occurs in a lecture.

Another important aspect for the students is the exam phase. Many write their exams in the semester break and therefore have little time for recreation. Thus they suggest more room for leisure time between the last exam and the start of the next semester. Another proposal is to let students decide democratically over the dates of their exams, e. g. via scheduling tools like doodle. Having block release courses is another idea to help the students focus and therefore to concentrate better.

More space or the more efficient use of space for learning and studying is important, since many students can't concentrate very well at home. One approach is to capture every seat in e. g. libraries or study halls and display them on a digital platform. Students can log onto that platform and see where seats are still available. Then they sign on in that room and thus give notice that they soon will arrive in that room. Once they arrive, a staff member refreshes the status of available seats of the website. If someone leaves the room and doesn't come back after 30 min, the seat will be marked as available again.

For a better time management, it would be useful to be able to buy all the needed learning material needed for one semester at one location, e. g. the university's library.

This system would work even better, if students could already order everything they need online in advance.

Regarding evaluation, it would help to have some binding guidelines like in quality management which are obligatory for every university. This national independent evaluation system could cover criteria like organization, outline of the course, articulation of the teacher, use of multimedia etc. Another idea is to let external agents visit unheraldedly and let them monitor and evaluate the lectures.

### *4.3 Digital Technologies in Lectures*

Half of the ideas in this field encompass the equipment of lecture halls. To fit an auditorium with headphone connections would result in the fact that lecturers can be understood clearly by everyone. It would also minimize the general noise level. A special interface installed on each desk could support the interaction of the lecture. A so called idiot buzzer (short for **I di**d n**o**t get i**t**) would give the students the opportunity to give instant feedback on the content of the lecture. The students strongly point out that this kind of system needs to be prepared for misusage. This could be realized by tracking the frequency of each button being used and blocking it, if it is used at an abnormal level.

With a simple website, teachers can perform quiz games in the lecture hall. It would be enough if the website provided buttons with a, b, c and d. The questions can then be put up spontaneously within the lecture or of course can also be prepared in advance. The students can log onto the website via their laptops or smartphones.

Two ideas deal with technical gadgets. One is about using green laser pointers, because they can be seen easier than red ones. Another covers the usage of smart pens, by teachers or by students. To be able to relate to the build-up of a mathematical equation or a drawing helps the students with their understanding process.

## 5 Discussion of Results

At the beginning of this paper we opened up the question, if students are competent, active and constructive partners in terms of improving teaching and learning in engineering education. In order to judge the competence of students, we wanted to see if the topics of the students match the topics the engineering education community currently deals with. Therefore we scanned the programmes, topics and session themes of the following conferences in 2012:

- 119th ASEE Annual Conference & Exposition, San Antonio
- IEEE International Conference on Teaching, Assessment and Learning for Engineering (TALE), Hong Kong
- World Engineering Education Forum (WEEF), Buenos Aires
- 40th SEFI Annual Conference, Thessaloniki

- IEEE Educon, Marrakesh
- 4th International Symposium of Engineering Education (ISEE), Sheffield
- International Conference on Innovation, Practice and Research in Engineering Education (EE), Coventry

The topics of *virtual learning environments* as well as learning technologies appear very often on the programmes of these conferences. The exact terms and notions vary slightly. Sub-topics are e. g. game based virtual labs, microcontrollers, tablet PCs (ASEE), online/e-learning, blended learning, computer-based learning, courseware technologies (TALE), educational technology in engineering (WEEF), Information and Communication Technologies (SEFI), IT's and Engineering Pedagogy (Educon), learning technologies - differences in the perceptions of students and educators (ISEE) or technology-supported learning (EE).

In the authors' opinion, the students' ideas within the topic *virtual learning environments* were the most innovative, like the video contest, and also easy to implement, like the virtual consultancy hours. This might be an indicator of new skills and interests of a generation of students who grew up with digital media, which older generations of teaching staff don't have. Various times it became clear that the students didn't consider learning in virtual environments as a substitute for studying in a brick-and-mortar university, but as a supplement. The ideas for digital technologies are mostly innovative, but also hard to implement like the interactive desks. Since *virtual learning environments* and *digital learning technologies* match the themes discussed by the engineering education community, the authors consider the students as competent partners in the improvement of teaching and learning in these two areas.

In the engineering education community, organizational aspects only appear rarely and if, on a more strategic level. It is referred to as curriculum development and quality assurance (SEFI), accreditation and regulations (ISEE) or leadership and administration (TALE). The ideas in the topic organization and resources were rather common and simple and in parts reproduce a one-sided view, like simply demanding more personnel.

As we have seen, students can definitely be considered as constructive partners. Only very few exceptions took the chance to criticize the whole university system. As almost three-quarters of all the e-mails consist of solution-oriented text, this characteristic has proven right within this study.

Compared to other online engineering idea contests such as the Australian Make it so Campaign in 2010, where nearly 7000 ideas were submitted within 12 weeks, the participation rate seems devastatingly low. One big difference is that on www.makeitso.org.au, the submissions were public and people could comment on each other's ideas [12]. This way, the contest is even more open than so far in *OpenBologna*. Although the conditions of the two contests are quite different as well, this might be a reason for the relatively low participation rate. For the next idea contest within TeachING-LearnING.EU, it will be considered to follow this more open approach.

## 6 Conclusions

We have seen the impact students can make in the improvement of teaching and learning, but we also saw the boundaries of this strategic instrument. The analysis of e-mails submitted by students in idea contests has shown that students sometimes have difficulties to see the university through a teacher's or administrator's eye which partly results in unrealistic demands. But for most parts, it became obvious that students can add valuable ideas to the pool of possibilities of how to improve curricula in engineering education. Especially innovations in digital technologies and aspects about the concept of a virtual university can be considered as their area of interest. In this field, students' opinions and contributions can be a great help for teaching and administration staff. In TeachING-LearnING.EU, this comprehension leads to a stronger focus on topics like *virtual learning environments* and *digital technologies* within the strategic instrument of *OpenBologna*. The next step in research on the effectivity of the strategic instrument is to analyze how many and what kind of ideas of the students are going to be "adopted" by teaching staff in the first step, and then actually going to be implemented in a second step. This will add another important aspect to the question of how students are integrated in curriculum development in the best possible way.

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# Verbesserung der Lernerfahrung durch die Integration des Virtual Theatres in die Ingenieursausbildung

**Katharina Schuster, Daniel Ewert, Daniel Johansson, Ursula Bach, René Vossen und Sabina Jeschke**

**Zusammenfassung** In ingenieurwissenschaftlichen Studiengängen zählen praktische Erfahrungen sowie das Verständnis für die praktische Relevanz von Lerninhalten zu den Voraussetzungen eines erfolgreichen Studiums. In Grundlagenfächern wie Physik oder Chemie werden praktische Erfahrungen meist experimentell durch Laborarbeit gesammelt. Ein weiterer verbreiteter Ansatz zur Herstellung praktischer Relevanz sind Praktika oder Exkursionen. Aus Sicherheits- und Kostengründen wie auch aufgrund der Komplexität industrieller Produktionsstätten ist es für Studierende jedoch nicht möglich, solche Industrieanlagen frei zu erkunden und dort eigenständig zu experimentieren.

Um diese Problematik zu umgehen, können Industrieanlagen in virtuellen Umgebungen nachgebaut werden. In Simulationen oder Lernspielen (Serious Games) werden die Eigenschaften und Prinzipien einer Industrieanlage mit entsprechenden Kursinhalten verknüpft und dadurch nachvollziehbar gemacht. In virtuellen Lernumgebungen können Prozesse der Wissensaneignung selbst gesteuert werden. Es können Experimente durchgeführt werden, die unter physisch-realen Bedingungen zu gefährlich oder zu teuer wären. Weiterhin können Orte erschlossen werden, die ansonsten nicht erreichbar wären – sei es weil sie räumlich zu weit entfernt oder zeitlich in der Vergangenheit oder in der Zukunft liegen.

Ein Nachteil des Lernens mit Simulationen besteht in der Künstlichkeit des virtuellen Zugangs. Neben der Art der grafischen Gestaltung einer virtuellen Lernumgebung liegt häufig die Antwort für den Grund auf der Seite der Hardware. Natürliche Nutzerschnittstellen (engl. natural user interface, NUI) für Visualisierung, Navigation und Interaktion können eine authentischere Lernerfahrung als am PC ermöglichen und somit den Wissenstransfer des Gelernten auf spätere Anwendungssituationen erleichtern. In Mixed-Reality Simulatoren wie dem Virtual Theatre werden die Nutzerschnittstellen Head-Mounted Display, omnidirektionaler Boden und Datenhandschuh integriert und ermöglichen so eine uneingeschränkte Kopf- und Fortbewegung zur freien Erschließung virtueller Lernumgebung. Nach einer

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Beschreibung des technischen Aufbaus des Virtual Theatres beschreibt das Paper einen medienpsychologischen Forschungsansatz, mit dem der Zusammenhang von immersiver Hardware und Lernerfolg gemessen werden kann. Das Paper schließt mit einem Ausblick auf den Einsatz des Virtual Theatres in der Ingenieurausbildung.

**Schlüsselwörter** Natural User Interfaces · Mixed-Reality · Immersion · Virtual Learning Environments

## 1 Einleitung

Es ist eine anerkannte Tatsache, dass Studierende der Ingenieurwissenschaften praktische Erfahrungen sowie konkrete Bezüge zur beruflichen Praxis benötigen, um ein ganzheitliches Verständnis ihrer Fachdisziplin erlangen zu können. In Grundlagenfächern wie Physik oder Chemie werden praktische Erfahrungen meist experimentell durch Laborarbeit gesammelt. Ein weiterer verbreiteter Ansatz zur Herstellung praktischer Relevanz sind Praktika oder Exkursionen. Aus Sicherheits- und Kostengründen wie auch aufgrund der Komplexität industrieller Produktionsstätten ist es für Studierende jedoch nicht möglich, solche Industrieanlagen frei zu erkunden und dort eigenständig zu experimentieren. Zum einen mit Blick auf die Produktion, da der stetige Produktionsfluss gewährleistet und Maschinen vor Beschädigung geschützt werden müssen. Zum anderen müssen Studierende selbst vor Verletzungen bewahrt werden, die z. B. durch unsachgemäße Maschinenbedienung sowie den Kontakt mit giftigen oder ätzenden Substanzen zustande kommen könnten. Der große Bedarf von Seiten der Studierenden scheitert folglich schnell am Machbaren.

Um die oben genannte Problematik zu umgehen, können Industrieanlagen in virtuellen Umgebungen nachgebaut werden. In Simulationen oder Lernspielen (Serious Games) können die Eigenschaften und Prinzipien einer Industrieanlage mit entsprechenden Kursinhalten verknüpft und dadurch nachvollziehbar gemacht werden. Ein Nachteil von Simulationen besteht häufig in der Künstlichkeit der Lernerfahrung. Normalerweise interagieren Nutzer/innen mit einer virtuellen Umgebung über einen PC. Am Beispiel der Industrieanlage wird diese auf einem Monitor angezeigt und das Sichtfeld durch eine Tastatur oder eine Maus gesteuert. Interaktionen mit virtuellen Objekten sowie Fortbewegung erfolgen über die gleichen Schnittstellen. Auf diese Weise überträgt der Nutzer oder die Nutzerin den Kontrollmodus des Computers auf die Aktionen seiner grafischen Repräsentation, dem Avatar.

Natürliche Nutzer/innenschnittstellen für Visualisierung, Navigation und Interaktion können eine authentischere Lernerfahrung als am PC ermöglichen und dazu führen, dass Studierende regelrecht in die virtuelle Welt eintauchen können. In diesem Zusammenhang spricht die Fachwelt häufig von Immersion – einem Bewusstseinszustand, auf den später im Rahmen dieses Beitrags noch näher eingegangen wird. Für eine erhöhte Immersion benötigt der Nutzer oder die Nutzerin eine nahtlose 3D-Sicht der virtuellen Umwelt. Diese wird häufig durch Head Mounted Displays

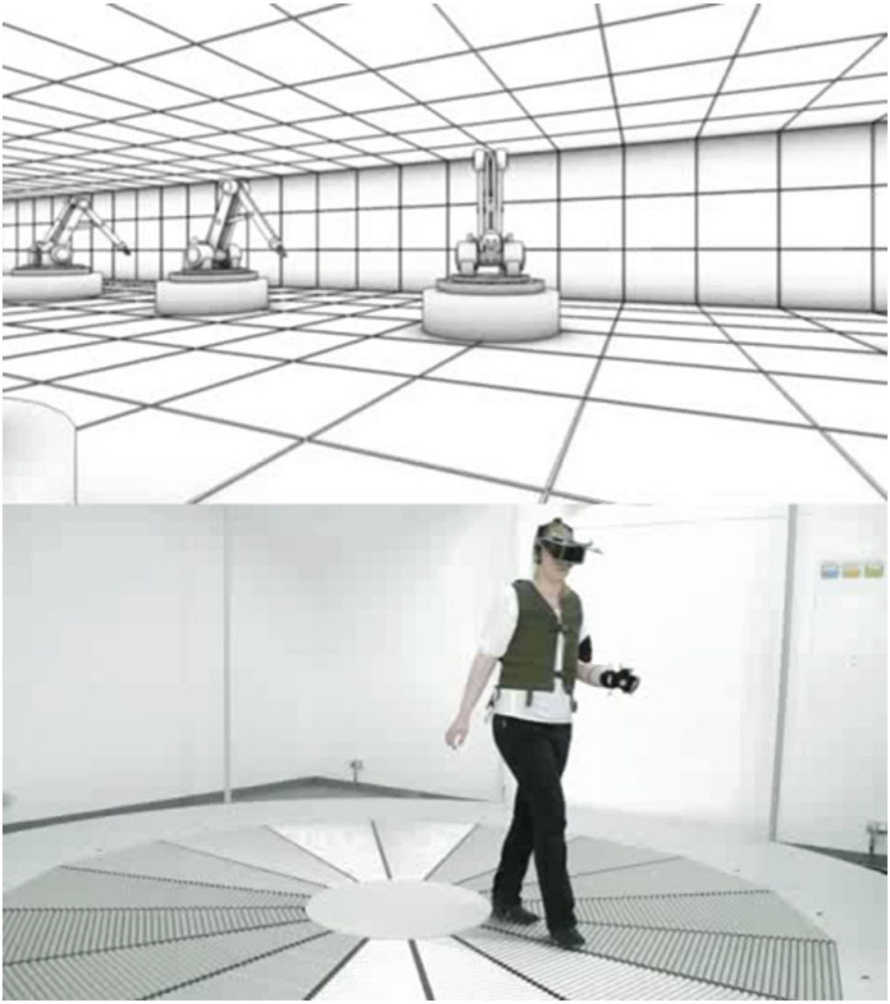

**Abb. 1** Das Virtual Theatre mit Nutzerin und (vereinfachter) virtueller Umgebung

(HMDs) realisiert. Für eine natürliche Navigation in der virtuellen Umgebung können omnidirektionale Laufbänder verwendet werden, die eine freie und unbegrenzte Bewegung ermöglichen und die nutzende Person doch an einem physisch klar begrenzten Ort lassen. Durch Datenhandschuhe kann der Nutzer bzw. die Nutzerin intuitiv mit der virtuellen Umgebung sowie den Objekten, die sich in ihr befinden, interagieren. Die beschriebenen Komponenten – HMD, omnidirektionales Laufband und der Datenhandschuh – sind im so genannten Virtual Theatre integriert [1]. Abbildung 1 zeigt die Nutzung des Virtual Theatres sowie ein exemplarisches Anwendungsszenario für die Lehre in den Ingenieurwissenschaften. Im Folgenden werden die technischen Komponenten des Virtual Theatres näher beschrieben. Anschließend wird der Begriff der Immersion erläutert sowie auf weitere Aspekte eingegangen, die die Wahrnehmung und das Verhalten der nutzenden Personen betreffen. Am Ende des Beitrags werden didaktische Prinzipien vorgestellt, die bei der Entwicklung von Lernszenarien für die Ingenieurausbildung berücksichtigt werden müssen sowie exemplarische Szenarien vorgestellt. Der Beitrag schließt mit einem Ausblick auf weiterführende Forschung am und mit dem Virtual Theatre.

# 2 Technische Beschreibung des Virtual Theatres

## *2.1 Hardware Komponenten*

### 2.1.1 Omnidirektionaler Boden

Der Nutzer oder die Nutzerin des Virtual Theatres kann sich frei bewegen, indem er oder sie einfach die gewünschte Richtung ansteuert. Der omnidirektionale Boden besteht aus 16 trapezförmigen Elementen. Diese sind aus je 16 festen Rollen zusammengesetzt, die nach außen hin breiter werden. Die Elemente haben an der kurzen Grundseite einen gemeinsamen Ursprung und sind im Mittelpunkt über eine unbewegliche Plattform miteinander verbunden. Die Laufrollen werden von unten von einem Riemenantrieb bewegt, um die Abstände zwischen den einzelnen Elementen zu minimieren. Auf der Plattform in der Mitte des Bodens kann sich die nutzende Person bewegen, ohne die Bodenbewegung zu starten. Abbildung 2 zeigt den Aufbau des omnidirektionalen Bodens als CAD-Modell. Ohne die unbewegliche Mittelplattform würde die Bodenbewegung dazu führen, dass die Füße des Nutzers oder der Nutzerin in der Mitte des Bodens aneinander gezogen werden. Wenn die nutzende Person die Mittelplattform verlässt, rotieren die Rollen der Elemente des Bodens gemäß eines Kontrollalgorithmus automatisch in Gegenrichtung zu der Bewegung des Nutzers bzw. der Nutzerin [2].

### 2.1.2 Head Mounted Display (HMD)

Das Virtual Theatre ermöglicht der nutzenden Person eine nahtlose 3D-Visualierung der virtuellen Umgebung. Jede Kopfbewegung wird direkt in der Simulation widergespiegelt, so dass die nutzende Person in seiner oder ihrer Sicht nicht eingeschränkt

**Abb. 2** CAD Modell des omnidirektionalen Bodens

**Abb. 3** HMD mit angefügten Infrarot-Markern

ist. Das visuelle sowie das auditive Feedback wird über ein zSight HMD realisiert [3], welches ein stereoskopisches 70° Sichtfeld mit SXGA-Auflösung für jedes Auge erstellt. Der Audiosound erfolgt über an der Brille befestigte Kopfhörer, die Lautstärke kann von der nutzenden Person über ein kleines Rad kontrolliert werden. Das HMD wiegt 450 g. Über einen Drehknopf am Ober- sowie am Hinterkopf kann das HMD auf die individuelle Kopfgröße der Nutzer/innen eingestellt werden. Ein kleiner Drehknopf zwischen den Linsen regelt den Augen-Nasen-Abstand. Über kleine Räder unterhalb der Linsen kann die Auflösung der Mini-Displays an die individuelle Sehstärke angepasst werden. Abbildung 3 zeigt das HMD sowie die an ihm befestigten Infrarot-Marker.

### 2.1.3 Datenhandschuh

Handgesten können erkannt werden und die Simulation sowohl manipulieren als auch kontrollieren. Um in der virtuellen Umgebung mit Elementen aus der Umwelt interagieren zu können, erhält die nutzende Person einen Datenhandschuh, der eine Steuerung über natürliche Handbewegungen ermöglicht. Diese werden von 22 Sensoren empfangen, die im Datenhandschuh [4] eingearbeitet sind. Zurzeit ist nur ein Datenhandschuh in das System des Virtual Theatre integriert. Objektmanipulation oder zweihändige Gestenerkennung gestaltet sich derzeit noch als verhältnismäßig zu komplex, wenn man den Entwicklungsaufwand dem Nutzen gegenüberstellt. Dennoch ist die spätere Integration eines zweiten Datenhandschuhs möglich. Abbildung 4 zeigt den Datenhandschuh sowie die Darstellung der Handgesten in einer virtuellen Umgebung.

### 2.1.4 Tracking-System

Das Virtual Theatre ist mit zehn Infrarotkameras ausgestattet, um die Bewegungen der nutzenden Person zu registrieren. Die Kameras zeichnen die Positionen der

**Abb. 4** Datenhandschuh und Darstellung in einer virtuellen Umgebung

Infrarot-Marker auf, die mit dem HMD und dem Datenhandschuh verbunden sind. Die Position des HMD dient zugleich als Input für die Bewegungssteuerung des omnidirektionalen Bodens. Die nach innen gerichtete Geschwindigkeit der Rollen wird linear mit der Distanz des HMDs zum Zentrum des omnidirektionalen Bodens gesteigert – je weiter der Nutzer oder die Nutzerin vom Zentrum entfernt ist, desto schneller laufen die Rollen. Die Position des HMDs dient zudem der Steuerung der Sicht der nutzenden Person innerhalb der virtuellen Umgebung. Die Position des Datenhandschuhs dient der Repräsentation der Hand innerhalb der virtuellen Szenerie. Außerdem kann über die Position des Handschuhs im Notfall eine Systemabschaltung eingeleitet werden. Sobald die Hand unter eine Grenze von 0,5 m bewegt wird, z. B. falls die nutzende Person stürzen sollte, wird jede Bewegung des omnidirektionalen Bodens mit sofortiger Wirkung gestoppt.

#### 2.1.5 Integration der verschiedenen Komponenten

Die Systemarchitektur des Virtual Theatres ist in Abb. 5 dargestellt. Die fixen Komponenten Trackingsystem und omnidirektionaler Boden kommunizieren mit der Hardware-Steuerung über kabelbasierte Kommunikationskanäle. Um der nutzenden Person uneingeschränkte Bewegung zu ermöglichen, erfolgt jegliche Kommunikation der Hardware, die sich direkt an dem Nutzer oder der Nutzerin befindet, drahtlos (WLAN).

### *2.2 Software Setup*

Der Server des Virtual Theatres wird von zwei Computern betrieben, die unterschiedlichen Zwecken dienen. Der Hardware-Control-Server analysiert die Daten

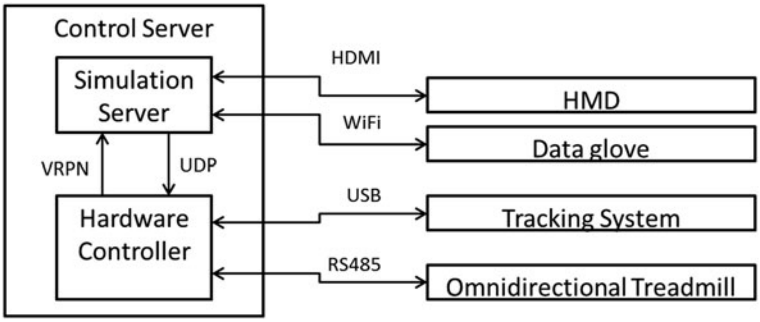


**Abb. 5** Systemarchitektur des Virtual Theatres

der Infrarotkameras und regelt den omnidirektionalen Boden. Um die Bewegungen der nutzenden Person auszuwerten, werden OptiTrack Tracking Tools [5] verwendet. Die Information über die Position wie auch die Geschwindigkeit des Bodens wird dem Simulationsserver durch vrpn [6] zugesendet. Hierbei handelt es sich um eine gerätunabhängige und netzwerktransparente Schnittstelle zu Virtual Reality Umgebungen. Der Simulationsserver ist für die High Level Steuerung verantwortlich und stellt die virtuelle Umgebung bereit. Hierfür wird der Toolkit Vizard Virtual Reality [7] verwendet. Die 3D-Modelle für virtuelle Umfelder werden mit Blender [8] erstellt und können in Vizard geladen werden.

## 2.3 *Einschränkungen*

Zurzeit kann sich die nutzende Person frei in der virtuellen Welt bewegen und bekommt Feedback in visueller und auditiver Form. Zusätzliche Simulationskomponenten, wie z. B. Temperaturregler oder Luftströmungen sind generell möglich, jedoch nicht Teil der derzeitigen Szenarien. Die parallele Nutzung durch mehrere Personen ist im Virtual Theatre nicht möglich: Der Boden verfügt nur über einen Motor und die Rollen können nicht unabhängig voneinander angesprochen werden. Auch wenn theoretisch mehrere Personen mit Infrarot-Markern ausgestattet und vom Tracking-System verfolgt werden können, so können nur die Daten einer Person verwendet werden, um den Motor entsprechend zu regeln.

Beobachtende können die Aktionen der nutzenden Person zwar an Bildschirmen verfolgen, jedoch nicht direkt mit der virtuellen Umwelt interagieren. Kooperative Szenarien, in denen die Beobachtenden die nutzende Person anweisen und in anderer Weise unterstützen oder ihm bzw. ihr sogar mit Hilfe eines klassisch gesteuerten Avatars assistieren, sind prinzipiell möglich. Für den Lehreinsatz ist das Virtual Theatre jedoch nur für kleine Kursgrößen geeignet, was u. a. durch die begrenzte Raumkapazität der Halle bedingt ist, in der sich der Simulator befindet. Dies muss bei der didaktischen Konzeptionierung entsprechender Seminare in den Ingenieurwissenschaften berücksichtigt werden. Die Einzelnutzung ohne den organisatorischen Rahmen eines Kurses ist natürlich auch möglich, jedoch nicht unbedingt kosteneffizient, da aus Sicherheitsgründen stets ein/e geschulte/r Simulationsleiter/in anwesend sein muss. Eine interessante Forschungsfrage lässt sich aus der Theorie des beobachtenden Lernens von Albert Bandura [9] ableiten. So könnte ein zukünftiger Untersuchungsgegenstand sein, ob Studierende, die nur die Beobachtungsperspektive und nicht die der nutzenden Person einnehmen, ähnliche Lernerfolge verzeichnen können, wie tatsächliche Nutzer/innen.

## 3 Nutzer/innenzentrierte Untersuchungen zu Wahrnehmung und Verhalten

### *3.1 Konzeptioneller Hintergrund von Immersion*

Generell dienen natürliche Nutzer/inn/enschnittstellen immer dem Zweck, die Mensch-Computer-Interaktion zu erleichtern, Illusionen zu erzeugen und bestimmte Situationen so realitätsnah wie möglich zu imitieren. Ziel ist es, bei dem Nutzer oder der Nutzerin den Eindruck zu erwecken, sich tatsächlich in der virtuellen Umgebung zu befinden. Bevor das Virtual Theatre in der Ingenieurausbildung eingesetzt wird, sind wissenschaftliche Erkenntnisse über die Wahrnehmung der Lernsituation und über den tatsächlichen Lernerfolg notwendig. Deswegen wird die weitere Entwicklung der Hardware und der Lernszenarien von unterschiedlichen psychologischen Studien begleitet. Eine Erklärung der experimentellen Gestaltung dieser Studien erfolgt nach einem näheren Blick auf den Begriff der Immersion, der häufig im Kontext der Realisierung immer realistischerer Simulationen verwendet wird.

Bekannte Beispiele realitätsgetreuer Situationsimitationen sind Flug- und Fahrsimulatoren oder Spielkonsolen im Unterhaltungsbereich. Der Begriff der Immersion wird diesbezüglich als ein objektives, steigerbares Maß benutzt, um zu beschreiben, inwieweit technische Eigenschaften dazu beitragen, die Illusionen zu erschaffen. HMDs gelten generell als gute Voraussetzung für Immersion. Ein HMD mit einer 101° Sicht gewährleistet eine intensivere Immersion als ein HMD mit einer Sichtweite von 100°. Ein Simulator wie das Virtual Theatre, in dem man frei herumlaufen kann, erzeugt folglich eine höhere Immersion, als ein Simulator der dies nicht ermöglicht [10].

In Spieler/innenkreisen wird der Begriff für die Erfahrung verwendet, inwiefern man sich in der Welt des Spiels „verlieren" kann. Schon eine oberflächliche Durchsicht verschiedener Gaming Foren und Blogs verdeutlicht, dass die Bedeutung von Immersion mehrdeutig und facettenreich ist. Die Beschreibungen, die diesen Begriff begleiten, reichen von der Fähigkeit eines Spiels „dich von der realen Welt los zu reißen und dich mit tatsächlichen psychischen Erfahrung zu überschwemmen, voll von emotionaler Aufruhr und Konflikten" [11] bis hin zu „der Fähigkeit, den Spieler (/ die Spielerin) in andere Elemente als den Charakter und die Geschichte des Spiels miteinzubeziehen" [12]. Der Begriff Immersion besitzt hier eine positive Konnotation und gilt als Qualitätssiegel für Computerspiele. Bezüglich der Hardware verdeutlicht die Entwicklung immer neuer Schnittstellen im Unterhaltungsbereich, wie der Nintendo Wii oder der Kinect für die Xbox Konsole, den Wunsch nach einer natürlicheren Steuerung. Obwohl sich Hardware-Entwickler/innen und die Gaming Community über die Bedeutung von Immersion weitestgehend einig sind, ist der Begriff noch nicht vollständig definiert worden. Weiterhin wurde noch nicht einheitlich geklärt, was Immersion aus psychologischer Sicht ausmacht und welche Effekte sie hat, vor allem wenn das Ziel nicht Unterhaltung sondern Lernen ist.

In einer ersten Annäherung kann Immersion als „der subjektive Eindruck, dass jemand eine umfassende und realistische Erfahrung macht“ [13] definiert werden. Die Idee absorbierender und anregender Erfahrungen ist jedoch nicht neu und es existieren darüber hinaus diverse weitere Begriffskonzepte, die der Idee von Immersion ähneln und in Beziehung zu ihr stehen. Involviertheit, räumliche Präsenz und Flow gelten als Schlüsselkonzepte, um immersive Erfahrungen zu erklären, auch wenn die genauen Definitionen und Bedeutungszuschreibungen je nach Autor/in variieren. Involviertheit beschreibt einen psychischen Zustand, der daraus resultiert, dass jemand all seine Energie und Aufmerksamkeit auf ein Set an Reizen, Aktivitäten oder Ereignissen lenkt. Der Grad an Involviertheit hängt dabei auch von der Wichtigkeit ab, die das Individuum diesen Reizen beimisst [14].

Während Flow die Involviertheit in eine Aktivität beschreibt, bezieht sich Präsenz auf die räumliche Sinneswahrnehmung in einer medialisierten Umgebung [15]. Das auf Csikszentmihalyi [16] zurückgehende Konzept des Flows wurde von Rheinberg et al. auf Mensch-Computer-Interaktionen adaptiert. Hier beschreibt Flow das Gefühl vollkommener Konzentration, Kontrolle über die Aktivität, Klarheit über die Arbeitsschritte, flüssiges und automatisches Denken sowie „glatte“, wie von selbst fließende Handlungsabläufe. Des Weiteren meint Flow das Gefühl der kompletten Involviertheit, ein verändertes Zeitgefühl, das Gefühl der optimalen Herausforderung und einer gewissen Geistesabwesenheit, dem sog. „Verschmelzen“ von Selbst und Tätigkeit [17].

Eine Reihe von Studien zeigt, dass persönliche Charakteristika einen Einfluss auf Immersion haben. Weibel et al. [15] belegen, dass die Eigenschaften Offenheit für neue Erfahrungen, Neurotizismus und Extraversion der sogenannten Big Five Persönlichkeitszüge positiv mit Immersion korrelieren. Ein weiterer Persönlichkeitszug der in Verbindung mit dem Ausmaß der persönlichen Erfahrung in einer virtuellen Umgebung (VU) stehen soll, ist die Affinität zur Technik. Da das Virtual Theatre eine neue und innovative technische Entwicklung ist, wird erwartet, dass die Durchführung einer Aufgabe im Virtual Theatre als anregender empfunden wird als z. B. an einem Laptop, vorausgesetzt die nutzende Person weist generell eine Affinität zu Technik auf. Insbesondere bei einem Simulator, der wie das Virtual Theatre freie Bewegung ermöglicht, wird angenommen, dass kognitive Fähigkeiten wie räumliches Vorstellungsvermögen eine Auswirkung auf die individuelle Wahrnehmung oder Lernleistung haben.

Ein vollständiges Verständnis über das Zusammenspiel individueller Voraussetzungen und den Hardware-Charakteristika sowie über ihren Einfluss auf die von einer Person erlebte Immersion ist von großer Wichtigkeit für weitere Forschung

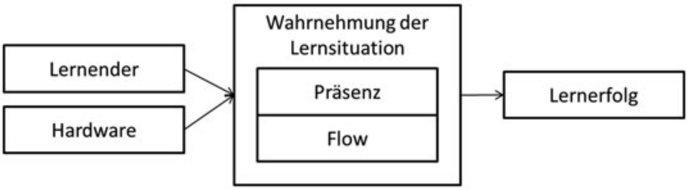


**Abb. 6** Erwarteter Zusammenhang zwischen Lernendem bzw. Lernender, Hardware, Wahrnehmung der Situation und Lernerfolg

am Virtual Theatre. Ein Einblick in die Gestaltung der Studien von menschlichen Erfahrungen und Verhalten erfolgt im nächsten Abschnitt.

## *3.2 Studiendesign*

Die Studien zu Wahrnehmung und Verhalten der Nutzer/innen im Virtual Theatre bewerten sowohl die subjektive Erfahrung der Präsenz und des Flows als zentrale Kenngrößen für Immersion, als auch den Lernerfolg. In Anlehnung an Witmer und Singer [14] folgen die Studien dem Ansatz, dass Präsenz- und Flow-Erleben in einer virtuellen Umgebung in Abhängigkeit individueller Unterschiede, Charakteristika der VU wie auch der Hardware des Simulators variieren. Individuelle Unterschiede, Merkmale und Fähigkeiten können in einer bestimmten VU das erlebte Präsenz- und Flow-Empfinden steigern oder mindern. Ebenso können sich verschiedene Charakteristika einer VU und der Hardware eines Simulators unterstützend oder beeinträchtigend auf die subjektive Erfahrung in einer Lernsituation auswirken.

Eine der wichtigsten Fragen innerhalb eines Bildungskontextes ist, ob die Erfahrung einer VU durch das Virtual Theatre zu einem besseren Lernergebnis führt als dieselbe Erfahrung über einen Laptop oder nur den Gebrauch eines HMDs. Wissensabfrage ist deshalb eine weitere wichtige Komponente des Studiendesigns. Die erwartete Beziehung zwischen Lernendem bzw. Lernender, Hardware sowie Wahrnehmung der Situation und des Lernerfolges ist in Abb. 6 dargestellt.

Um die Stärke des Effekts jeder Variable zu messen, werden unterschiedliche Studien im Virtual Theatre angesetzt. Eine erste Studie untersucht sowohl die immersive Qualität des Virtual Theatres als auch seine Möglichkeit zur Steigerung der Lernfähigkeit. Hierfür werden zwei randomisierte Studierendengruppen miteinander verglichen, indem sie in einer Lernsituation unterschiedliche Hardware benutzen. Die Hardware stellt die unabhängige Variable (UV) dar. Die Variable der virtuellen Umgebung und die der Aufgabe bleiben konstant: In einem Labyrinth müssen die Versuchspersonen umherlaufen, Objekte finden und sich deren Positionen merken. Die Experimentalgruppe muss die Aufgabe im Virtual Theatre absolvieren und die Kontrollgruppe löst dieselbe Aufgabe am Laptop. Das Wissensabfrageszenario bleibt wiederum für beide Gruppen gleich. Hierfür müssen die Versuchspersonen an einem Tablet PC die Objekte per Drag and Drop Steuerung an ihre korrekten Positionen auf einer Karte des leeren Labyrinths zuordnen. Der Tablet PC wurde gewählt, damit sich das Medium der Wissensabfrage sowohl für die Experimental- als auch für die Kontrollgruppe hinreichend vom Medium der Aufgabe unterscheidet. Die Genauigkeit der Position der Objekte wird vom Computer automatisch erfasst. Die persönliche Wahrnehmung der Lernsituation wird mit entsprechenden Skalen per Fragebogen gemessen. Dies erfolgt im Paper-Pencil-Verfahren, ebenfalls um unterschiedliche Medien bei Befragung und Aufgabe zu verwenden.

Eine zweite Studie konzentriert sich im Speziellen auf die immersive Qualität des omnidirektionalen Bodens. Auch in der zweiten Studie müssen die beiden Gruppen dieselbe Aufgabe in der gleichen Umgebung im Virtual Theatre absolvieren. Hierfür müssen sie auf einer italienischen Piazza frei umherblicken. Während sich die Experimentalgruppe aktiv innerhalb des Virtual Theatres bewegt, sprich: laufen muss, gebraucht die Kontrollgruppe lediglich die 3D-Sicht. Das aktive Bewegen stellt in diesem Fall die unabhängige Variable dar. Die Aufgabe ist dabei dieselbe wie in der ersten Studie, und die Studierenden müssen sich Positionen von Objekten auf der Piazza merken. Die Positionen werden wieder auf einem Tablet PC auf einer Karte der Piazza markiert. Gemessen werden erneut die persönliche Wahrnehmung der Lernsituation und die Genauigkeit der Position der Objekte.

Durch eine genaue Überprüfung des Zusammenhangs zwischen Nutzer/innen, Hardware und Lernerfolg ist es möglich, den Anteil der Immersion festzustellen, der durch die Persönlichkeit beeinflusst wird. Dadurch kann wiederum ein Profil erstellt werden, für welche Studierenden das Virtual Theatre am besten geeignet ist und am effektivsten wirkt. Außerdem können so maßgeschneiderte Lernszenarien für unterschiedliche Nutzerprofile entwickelt werden. Weitere Studien zu Wahrnehmung und Verhalten der Nutzer/innen im Virtual Theatre werden unter Einbeziehung der Szenarien erfolgen, die parallel speziell für die Ingenieurwissenschaften entwickelt werden. Diese Szenarien sowie die dahinter liegenden didaktischen Prinzipien werden im folgenden Kapitel erläutert.

# 4 Anwendung in der Lehre

## *4.1 Rahmenbedingungen*

Das Virtual Theatre bietet eine Vielzahl an Möglichkeiten für verschiedene Anwendungsgebiete, wodurch theoretisches Hintergrundwissen in praktischer Weise umgesetzt werden kann. Dies ist insbesondere dann sinnvoll, wenn eine reale Situation zu gefährlich, zu teuer oder generell nicht zugänglich ist. Am Lehrstuhl für Informationsmanagement im Maschinenbau wird das Virtual Theatre für die Lehre sowie als ein Teil eines Schüler/innenlabors des Deutschen Zentrums für Luft- und Raumfahrt (DLR) eingesetzt werden. In der Simulation wird es möglich sein, den Mars Rover Opportunity durch die eigenen Körperbewegungen zu steuern. Ein weiteres Szenario, dass sich vorerst noch in der Planung befindet, behandelt Inhalte und Bedienmöglichkeiten eines Atomkraftwerks.

### *4.2 Didaktische Prinzipien*

Es steht außer Frage, dass der Inhalt gewisser Themen in den Ingenieurwissenschaften nicht einfach anhand von Präsentationen vermittelt werden kann. Um den Lernprozess aktiv zu fördern, werden didaktische Methoden benötigt. So können Studierende beispielsweise theoretisches Wissen in praktischen Situationen wie einer Computer-Simulation mit Hilfe von Pop-Up Fenstern wiederholen. Dies hilft ihnen, das Wissen nachhaltig mit Erfahrungen und Hintergrundgeschichten zu verbinden, anstatt schlichtweg reine Fakten auswendig zu lernen.

Eine andere Methode, die in Verbindung mit dem Virtual Theatre steht, ist das explorative Lernen, wobei Inhalte nicht Stück für Stück wie in Vorlesungen, sondern offen und frei zugänglich präsentiert werden. Das Hauptprinzip dieser Methode ist, dass der Lernprozess von den Studierenden selbst kontrolliert wird und so die Möglichkeit gegeben ist, das Interesse und die Neugier der Studierenden zu wecken. Die Studierenden setzen sich entsprechend ihrer Interessen die Lernziele zu einem bestimmten Thema selbst und wählen eigenständig die Operatoren aus, die nötig sind, um das Lernziel zu erreichen. Beim explorativen Lernen erfolgen Lernprozesse dementsprechend nicht linear, sondern durch individuelle Schwerpunktsetzung. Falls der Lernprozess ins Stocken gerät können die Studierenden die vorangegangenen Lernschritte wiederholen und erst dann fortfahren, wenn diese erfolgreich bewältigt wurden. So bleibt jede/r Studierende stets im eigenen, für sich am besten geeigneten Lerntempo. Wird eine neue virtuelle Lernumgebung erstellt, dürfen mögliche Hemmfaktoren nicht unberücksichtigt bleiben. Dies ist auch deswegen notwendig, da jede/r Studierende über ein eigenes mentales Lernkonzept verfügt. Vermunt und Rijswik [18] haben diese subjektiven Lerntheorien von Studierenden analysiert und drei unterschiedliche Konzepte identifiziert. Das geläufigste Konzept (reproduktives Lernen) beschreibt Lernen als den Prozess der Übertragung von gesprochenem und geschriebenem Wissen ins Gedächtnis. Die zweite subjektive Lerntheorie bezieht sich auf den Gebrauch von Wissen. In diesem Fall ist Lernen ein wichtiger Prozess, um etwas später nachzuvollziehen. Das dritte Konzept, welches eher selten anzutreffen ist, betrachtet Lernen als Notwendigkeit zur selbstgesteuerten Identifikation und Konstruktion von Wissen.

Gesetzt den Fall, dass Studierende Lernen eher als einen Prozess des Nachbildens anstatt einer selbstgesteuerten Konstruktion von Wissen verstehen, wird angenommen, dass gleichzeitig ein großes Bedürfnis nach Instruktion durch Expert/inn/en vorherrscht [19]. Die Konsequenz, die daraus für das Virtual Theatre entsteht ist, dass Anwendungsszenarien auf unterschiedliche subjektive Lernmodelle anwendbar sein müssen. Das dritte Konzept könnte einfach in die Entwicklung von Szenarien eingebaut werden, indem die Abfrage oder Wiederholung von explizitem Wissen durch Pop-Up Fenster oder eine Begleitstimme aus dem Hintergrund erfolgt.

Computersimulationen bieten im Allgemeinen die Möglichkeit des Perspektivwechsels und ermöglichen Studierenden dadurch den Zugang zu normalerweise unzugänglichen Situationen. In einem zukünftigen Szenario, zum Beispiel dem einer Industrieanlage, könnte der/die Studierende die Abfertigung eines Produkts in einem

Produktionsablauf von Anfang bis Ende verfolgen und so wertvolles Verständnis für die Prinzipien eines solchen Prozesses erlangen. Andere Anwendungsbereiche könnten der Weg einer Container Box in einem logistischem Prozess oder auch die Reise durch den Körper des Menschen aus der Perspektive einer Blutzelle darstellen, ähnlich wie in der TV Serie Es war einmal . . . das Leben [20].

Ein vielversprechender Ansatz, der während eines Workshops mit Studierenden entstanden ist, ist das Game Based Learning (GBL). Computerspielen wird von Studierenden meist als freiwilliger Prozess und nicht als Lernprozess betrachtet, was einen großen Vorteil von GBL darstellt. Nichtsdestotrotz lernen wir durch Spiele mit komplexen Zusammenhängen umzugehen, wie beim Schach [19]. Für das Virtual Theatre gibt es mehrere Möglichkeiten, bereits entwickelte Szenarien in Spiele abzuwandeln. Zuerst kann der oder dem Studierenden eine Mission oder ein Problem aufgetragen werden, das sie bzw. er dann lösen muss. Die oder der Studierende muss versuchen, das Problem oder die Mission nach eigenem Können und Wissen zu lösen (implizites Wissen). Für den Fall, dass die oder der Studierende nicht weiterkommt, hat sie bzw. er die Möglichkeit in einen Erklärungsmodus zu wechseln, in dem zusätzliche Informationen zur Verfügung gestellt werden. Der Wechsel der Modi kann sich jedoch auch hemmend auf die erlebte Immersion auswirken. Dieser Effekt muss in zukünftigen Studien ebenfalls untersucht werden. Eine zusätzliche Möglichkeit ist es, verschiedene Level in das Spiel oder die VU einzuarbeiten. In einer industriellen Szenerie müssten Studierende zum Beispiel anfangs leichtere Maschinen bedienen, um die grundliegenden Prinzipien zu verstehen um dann an komplexeren Situationen arbeiten zu können, in welchen Geräte defekt sind und repariert werden müssen.

Diese Übersicht erhebt keinen Anspruch auf Vollständigkeit. Sie soll aber verdeutlichen, welch großes Potenzial sich durch das Virtual Theatre für die Lehre in den Ingenieurwissenschaften und der Verbesserung der Lernerfahrung ergibt. Im Folgenden werden zwei sich in der Entwicklung befindende Lernszenarien als Anwendungsbeispiele exemplarisch beschrieben.

### *4.3 Szenario 1: Mars Mission*

Beim Marsszenario kann sich die nutzende Person frei auf der Oberfläche des Planeten Mars bewegen. Das Szenario stellt eine Reproduktion der Landebahn des Rover Spirits dar und basiert auf einem Höhenprofil der Landebahn sowie hochauflösenden Fotos der Mars Mission. Innerhalb der Umgebung werden genaue Modelle der verschiedenen Mars Rovers platziert. Abhängig von Position und Sicht des Benutzers oder der Benutzerin werden zusätzliche Informationen in Pop-Up Fenstern dargestellt. Abbildungen 7 und 8 zeigen Screenshots des Marsszenarios aus Sicht der nutzenden Person sowie aus der Perspektive einer Remote-Steuerung.

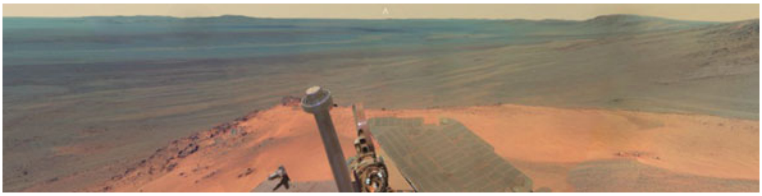

**Abb. 7** Panoramasicht vom Mars Rover (Eigentum der NASA)

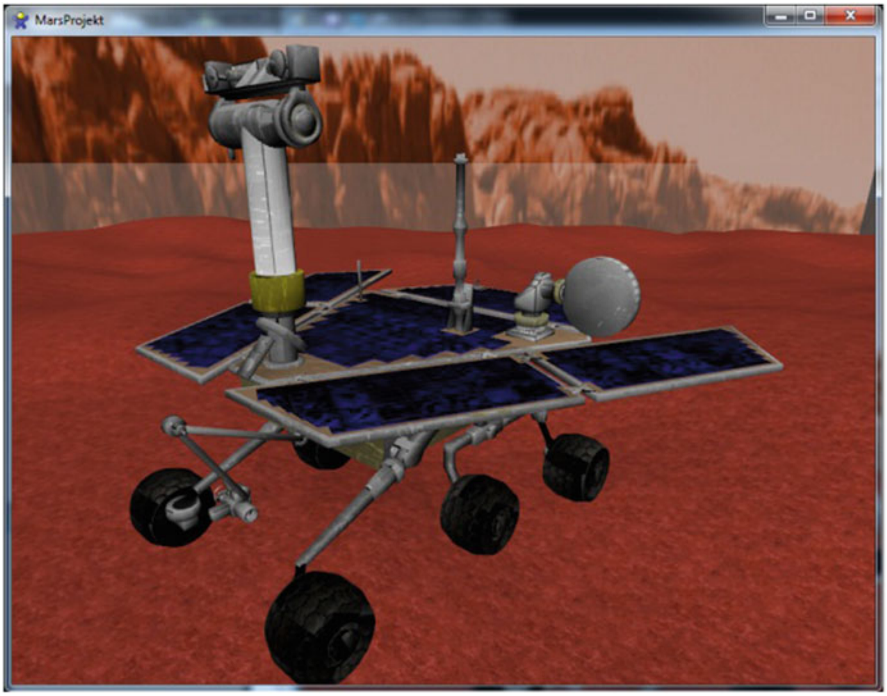


**Abb. 8** Model des Mars Rover oppurtinity

## *4.4 Szenario 2: Atomkraftwerk*

Das zweite Szenario beinhaltet die Simulation eines Kernkraftwerks. Studierende werden die Möglichkeit bekommen, den inneren Aufbau eines Atomreaktors zu besichtigen und frei in dieser Umgebung zu experimentieren. Naheliegende Interaktionen sind z. B. die direkte Einflussnahme auf Brennstoff und Kontrollstäbe sowie auf die Kühlung. Der Effekt jeder Beeinflussung wird sofort anhand der zugrunde liegenden Gleichungen in der virtuellen Umgebung angezeigt. Zusätzlich verweisen die unterschiedlichen Geräusche des Kontaminationsmessgeräts auf den Anteil der Verstrahlung. Abbildung 9 zeigt einen Screenshot des Szenarios

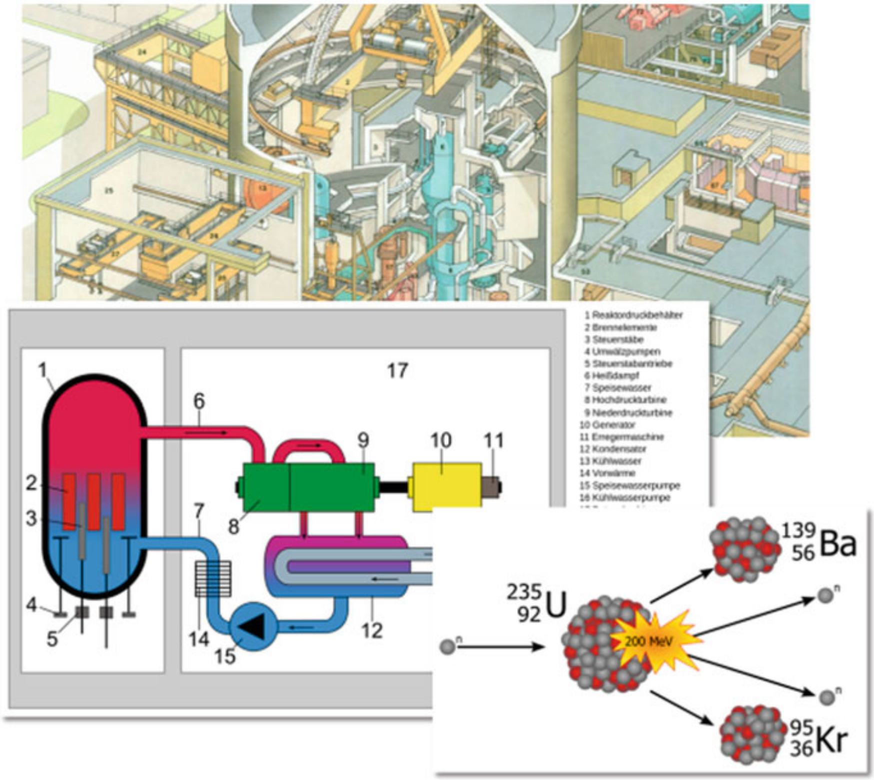


**Abb. 9** Schema eines Atomkraftwerks

aus Sicht eines Steuerungsraumes sowie zusätzliche Informationsdarstellungen zur Wissensvermittlung bzw. Vertiefung.

## 5 Zusammenfassung und Ausblick

In diesem Artikel wurde das Virtual Theatre als ein neues Werkzeug für exploratives Lernen innerhalb virtueller Lernumgebungen vorgestellt. Es wurden die technische Umsetzung und Integration der Hardware sowie der Software beschrieben. Weiterhin wurden erste Anwendungsmöglichkeiten vorgestellt und der Einfluss einer verstärkten Immersion auf Lernsituationen diskutiert. Zukünftige Lernszenarien werden industrielle Anwendungen, Produktionsanlagen und Raumfahrtszenarien fokussieren. Es wird ebenfalls in Betracht gezogen, das Virtual Theatre mit Remote-Laboren zu verbinden und so die Bewegungen der Nutzer/innen innerhalb der virtuellen Umgebung auf robotische Manipulatoren abzubilden. Erste Anwendungen in diesem Bereich werden auf Testanwendungen für Metallbiegung basieren.

Zukünftige psychologische Studien werden unterschiedliche Nutzer/innengruppen miteinander vergleichen. So ist es eine interessante Frage, ob Schüler/innen im Virtual Theatre leichter lernen als Studierende. In enger Zusammenarbeit werden die Erkenntnisse aus den Fachrichtungen der Informatik, der Didaktik, den Ingenieurwissenschaften und der Psychologie dazu führen, das gesamte Potenzial des Virtual Theatres für den Einsatz in der Lehre zu erfassen.

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# Creating an E-Learning Recommender System Supporting Teachers of Engineering Disciplines

**Elena Soldatova, Ursula Bach, René Vossen and Sabina Jeschke**

**Abstract** Numerous reviews and studies have shown that Learning Management Systems at university level often are lacking from a number of characteristics such as the support of various didactical approaches, the possibility to consider different specifics of engineering disciplines or a lecturer friendly interface. In this paper, a new recommender system is proposed for teaching staff of engineering disciplines; the novelty of the recommender system is that criteria used by the system are based on standards for engineering education in conjunction with the framework for pedagogical evaluation of Virtual Learning Environments. The suitability assessment scenario being suggested identifies the various needs of teaching staff member with regards to his/her course, teaching methods and also suggests tools that are necessary to increase functionality.

**Keywords** E-Learning · Engineering Education · Recommender System

## 1 Introduction

Several studies analysing the usage of Learning Management System (LMS) by the teaching staff of engineering disciplines [1] have revealed problems such as the lack of collaboration among the lecturers in terms of the LMS usage and the lack of help available on the LMS usage. As a result, not all teaching staff members are going to use LMS in the near future.

The reviews of LMSs currently used at the University College of Borås/Sweden, Duke University/USA [2] and the University of Alberta/Canada [3] show that most universities often lack flexibility, interactivity and the possibility to take into account factors such as staff expertise and institutional needs. As a result, most of the times LMS does not permit the academic staff to exploit the education potential of state of the art E-Learning technologies. Therefore, universities sooner or later need to tackle the problem of moving their courses to another platform.

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In conclusion, studies have shown that lecturers in general need more support when starting to use a LMS. Therefore, an appropriate recommender system that addresses the level lecturer expertise as well as the subject that he/she is teaching is needed. Although the proper use of the LMS by students is another important aspect, the target audience of this article has been restricted to teaching staff of engineering disciplines.

The IMA/ZLW&IfU has almost 40 years of experience in collaborating with the teaching staff of the engineering faculties of the RWTH in the area of developing better teaching approaches. Nowadays, more than 80 seminars aimed at the improvement of a teaching process are offered per semester. Therefore, our experience of communication with the teaching staff of the RWTH also has revealed the same drawbacks of LMSs which have been stated above and also found in studies. Furthermore, it has also been observed that local course websites and FTP servers are preferred over university LMS quite often. Some faculties are even known to have their own LMS.

Our goal is to create an E-Learning recommender system that can help teaching staff of engineering disciplines by providing recommendations on a selection of suitable E-Learning tools based on the criteria defined. The problem has been elaborated by using the framework for the pedagogical evaluation of virtual environments [4] in order to assess the needs of a teaching staff. Furthermore, the suitability assessment scenario for the recommender systems has been described and the as object diagram for future software engineering purpose has also been provided.

## 2 Background

### *2.1 Theory*

There is a commonly used division of E-Learning tools into Learning Management Systems (LMSs) and Course Authoring Tools (CATs). The E-Learning software overviews show that more than 400 LMSs and CATs are available [5]. Such systems require serious time investment in order to create the course and to educate at least one member of computer support on how to install and maintain the software [6].

A LMS provides mainly course management functionality and basic facilities of course authoring tools. For example, the most widely-used LMSs such as Moodle, Blackboard, Camillo and Sakai have a storage space, space for course description and WiKi as a tool for course contents. Course Authoring Tools provide to a course instructor functionalities to create an E-Learning content. Currently LMSs are much more adopted than CATs, although being only a part of wide E-Learning tools spectrum. Consequently, a lot of research about usage of LMSs is available.

The LMS/CAT division is sometimes problematic to apply in practice, for example Facebook, Twitter, Youtube do not perfectly fit into it, however these tools are included in the rating of top 100 e-learning tools [7]. These tools as well attract users with due to their ease of use and intuitive interfaces.

We will stick to more suitable for us classification of E- Learning Tools consisting of three levels [8]: the usage of internet, the usage of a platform and interactive contents. A "Level 1" is achieved when internet is used, "Level 2" is achieved when a platform and internet are used. A "Level 3" is achieved when all three criterias have been fulfilled, i. e., the internet, a platform, learning videos, multimedia and interactive elements are used in E-Learning. For later scope of the article we will focus on "Level 3". Scenarios corresponding to "Level1" and "Level 2" are used for a long time at the RWTH, "Level3" scenarios such as MOOCs, Virtual Laboratories are now being introduced at a big pace [9, 10].

## 2.2 Vision

The following working hypothesis is used for future work: "There are a number of well-defined and assessable criteria which assure the E-Learning tool suitability ("Level3" according to the above classification) for a course and an institution once they have been applied systematically."

Our goal is with regards to hypothesis to elaborate a number of criteria which assure the E-Learning tool suitability ("Level 3" according to above claassification) for a course and an institution once they have been applied systematically.

The overall goal is to create a recommender system for the teaching staff which shall assist them in choosing appropriate tools with regards to engineering specifics. The system is aimed at all those individuals who wish to use E-Learning tools in their courses and it also takes into consideration the level of user experience.

General goal of the IMA/ZLW & IfU is to support the academic staff in using the "Level 3" of the E-Learning tools hierarchy at the engineering faculties of the RWTH Aachen University. The specifics of various engineering education processes also needs to be addressed. However, it should be clearly stated that questions pertaining to the efficiency of the selected E-Learning tool in the learning process have been completely left out of the scope of our research.

## 2.3 Problem Elaboration

According to the definition [11], "E-Learning is learning facilitated and supported through the use of information and communications technology (ICT)". Consequently, both aspects of learning and of ICT tools need to be taken into account for criteria elaboration and consequently for creating the recommender system.

### *2.4 The Framework for Pedagogical Evaluation of Virtual Learning Environments*

The framework for pedagogical evaluation of Virtual Learning Environments (VLE) is described in article [4]. VLE is a collection of tools enabling the management of online learning, providing a delivery mechanism, student tracking, assessment and access to resources. VLE includes E-Learning tools therefore this framework is applicable to the scope of our work.

The framework is said to provide a clear set of requirements for evaluating the system's suitability for supporting the processes that form the basis of interactive learning. This framework is based on a system approach and therefore it has been chosen upon the other articles that were analyzing selected qualities of a learning process [12–16].

The framework combines a conversational model applied to the academic learning and a viable system model applied to the course management. Therefore "it helps in supporting pedagogical innovation (programme level), institutional management of programmes (module level) and students management of their own learning (learner level)".

The criteria used by the framework for suitability evaluation are as follows: degree of presentation and re-presentation of key concepts and ideas, degree of coordination of people, resources and activities, resource negotiation and agreement monitoring of learning, degree of self organization amongst learners and the adaptability of the module and the system.

Therefore the novelty of the system lies in the following: explicitly defined audience, choice of pedagogically sound criteria that are used to assess E-Learning tools, the needs of a teaching staff member, his/her current scenarios in E-Learning tools usage.. and to suggest new tools, the scenarios and tools suggested will be based on the Engineering educational standards with regards to the subject specifics, therefore making the scenarios and tools suggested for the teaching staff member pedagogically biased, scientifically explained and compliant with the quality of course when based on engineering standard.

## 3 Results

### *3.1 Criteria Profiling for Engineering Education*

The VLE framework has a universal character, therefore it can be used for engineering education. There are a number of standards of engineering education such as EC-2000 [17], CDIO [18], ABET [19], SPEC [20] that are used for the accreditation of engineering universities in the USA (ABET), UK (SPEC) and internationally (EC-2000, CDIO). These standards also serve as a basis for courses, goals identification, curriculum creation in the respective universities. We will stick to the CDIO standard and the framework criteria will be profiled according to the CDIO; this will be discussed later in the article.

## 3.2 Criteria Elaboration

The main idea is to use the framework [5] and standards for engineering education in order to formulate criteria that shall be used to provide recommendation. These criteria are as follows: degree of presentation and re-presentation of key concepts and ideas, coordination of people, resources and activities resource negotiation and agreement monitoring of learning, self organization amongst learners and the adaptability of the module and the system.

## 3.3 Rationale Towards the Recommender System

Suitability assessment and evaluation can be automated therefore we suppose to build a recommender system software. Herein below the suitability assessment scenario for a recommender system has been suggested and explained (Fig. 1). To begin with, here are examples of questions from the framework that correspond to the "Programme level" and criteria "resource negotiation and agreement: "Does the system allow specification of programme rules for delivering a module? Does it permit or provide a space for negotiation between programme managers and module tutor on resource questions? What tools does the system provide for teachers to present/express their ideas to students?"

Secondly, the CDIO standard imposes specific guidelines which will shape the specifics of question. As a result, the VLE assessment will be superceded with the CDIO assessment in applicable parts.

### 3.3.1 Requirements Collection Phase

From the criteria, a set of questions (similar to [21]) shall be formulated in order to identify the needs of the teaching staff member towards the E-Learning tool at all three educational levels (module, learner and programme). As well his current experience with E-Learning tools will assessed basing on the VLE framework criteria. Every answer will be assigned with a specific score. In order to quantify the answers the recommendations of the CDIO standard will be used in applicable parts. Therefore all collected answers will be quantified.

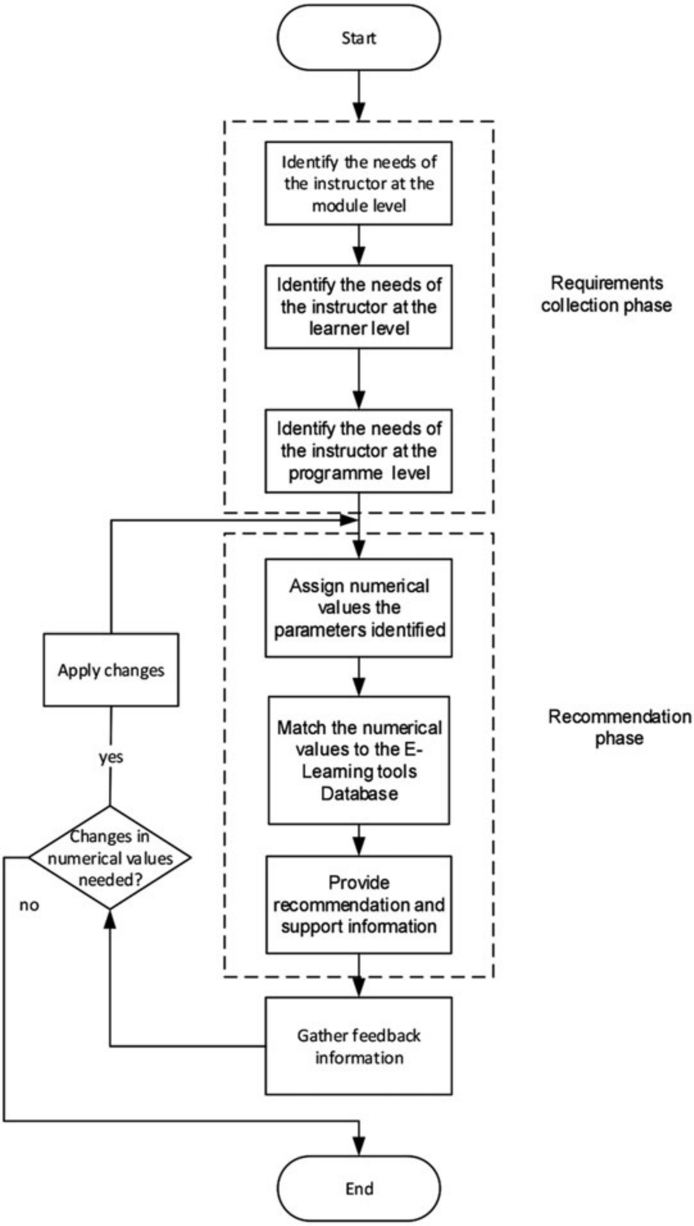



**Fig. 1** Suitability assessment scenario

| Criteria vs. Tool | Moodle | Blackboard | Twitter | Youtube | MS Word |
|---|---|---|---|---|---|
| **Module level** | | | | | |
| presentation and re-presentation of key concepts and ideas | 10 | 8 | 6 | 10 | 8 |
| coordination of people, resources and activities | 10 | 7 | 10 | 1 | 8 |
| resource negotiation and agreement | 10 | 5 | 3 | 1 | 7 |
| monitoring of learning | 5 | 10 | 8 | 0 | 0 |
| self organization amongst learners | 10 | 10 | 8 | 0 | 0 |
| adaptability of module and system | 5 | 3 | 0 | 0 | 0 |
| **Learner level** | | | | | |
| Learner-centredness | 10 | 10 | 0 | 0 | 0 |
| coordination of people, resources and activities | 10 | 10 | 10 | 0 | 0 |
| time management / planning | 10 | 10 | 0 | 0 | 0 |
| monitoring own learning | 9 | 3 | 0 | 0 | 0 |
| adaptation / reflection | 7 | 10 | 0 | 0 | 0 |
| **Programme level** | | | | | |
| Extensibility and integration | 6 | 7 | 3 | 2 | 1 |
| coordination of people, resources and activities | 10 | 8 | 0 | 0 | 0 |
| resource negotiation and agreement | 10 | 8 | 0 | 0 | 0 |
| monitoring of learning | 10 | 8 | 0 | 0 | 0 |
| self organization amongst learners | 10 | 8 | 2 | 0 | 0 |
| adaptability of module and system | 10 | 8 | 0 | 0 | 0 |

**Fig. 2** E-Learning tools database

### 3.3.2 Recommendation Phase

A logical mapping between the needs of the teaching staff member identified and the criteria in evaluation framework is performed. Basing itself upon the values obtained for each criteria in a requirements collection phase the match to E-Learning tools database shall be performed. The E-Learning tools database will contain records for various E-Learning tools which are evaluated using the framework [8]. However, the benchmarking shall be used in order to have a score for each of the three levels (module, learner and programme). The tools included in the database will then be chosen based on tools ratings, engineering specifics and by making a questionnaire of the teaching staff. As a result, the relevant pieces of advice can easily be provided.

The exemplary representation of the E-Learning tools database is provided in the Fig. 2. Each of these tools have been added to the database are multiply assessed according to the criteria of the framework [8]. The criteria are contained in the left column of the table. Each criterion gives a score from 1 to 10 for the said tool. The scoring will be done on basis of expert interviews and by using the recommendations for benchmarking the E-Learning Tools in [20] . However, one must note that the content of the database provided in the Fig. 3 simply aims at giving an idea of the inner view of the database; the scores themselves are not real.

The possibility of a feedback which may be needed when the instructors are not satisfied with the recommendation has also been well provided. The decision for changes can be made by a person after the processing of comments.

| Criteria vs. Tool | Recommended |
|---|---|
| **Module level** | Tool |
| presentation and re-presentation of key concepts and ideas | 8 |
| coordination of people, resources and activities | 8 |
| resource negotiation and agreement | 8 |
| monitoring of learning | 7 |
| self organization amongst learners | 10 |
| adaptability of module and system | 5 |
| **Learner level** | |
| Learner-centredness | 7 |
| coordination of people, resources and activities | 6 |
| time management / planning | 7 |
| monitoring own learning | 7 |
| adaptation / reflection | 7 |
| **Programme level** | |
| Extensibility and integration | |
| coordination of people, resources and activities | 8 |
| resource negotiation and agreement | 8 |
| monitoring of learning | 8 |
| self organization amongst learners | 8 |
| adaptability of module and system | 8 |

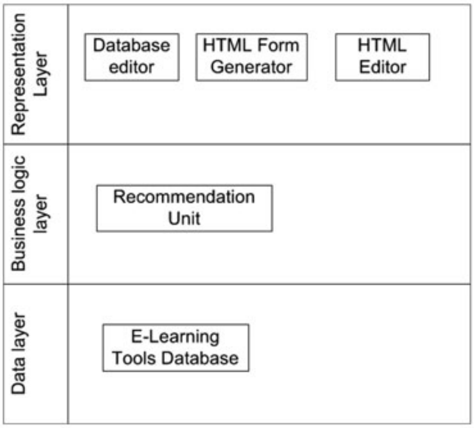
**Fig. 3** An example of the Recommendation Unit output

In the output screen of the system, the tool shall be suggested to the user and he/she will have an opportunity to obtain more information about the tool itself; to understand the reason behind the recommendation and to correct the recommendation by adjusting the criteria according to his/her personal feelings.

## *3.4 The Recommender System Structure*

A structural diagram (Fig. 4) illustrates the division of the system into the three layers: Representation layer, Business Logic Layer, Data Layer. Representation layer displays the information for users. Therefore, it consists of the database editor, the HTML Form Generator and the HTML Editor. The Business logic layer performs the logic calculations in the Recommendation phase with the help of a Recommendation Unit. The Data layer shall contain the E-Learning Tools Database that are to be used in Recommendation phase.

**Fig. 4** Structural diagram




# 4 Conclusion

The goal of this work was to address the problem of recommending E-Learning tools for a teaching staff of engineering disciplines by defining criteria that will be used to create an E-Learning recommender system.

The chosen criteria are based on the engineering standards of engineering education and the framework. The suitability assessment scenario for the recommender system has also been presented. The novelty of the recommender system lies in applying the framework to the engineering education, using the engineering standards to derive the questions for requirements collection phase and using the benchmarking of tools for the recommender phase.

The concept of the recommender system is presented at the early stages of system development. Therefore, future work must include a proper formulating of questions for the recommendation phase, the assignment and scoring of user answers and the careful benchmarking of available E-learning tools. A questionnaire of the teaching staff has also been planned. The questionnaire shall serve the following purposes: reveal new tools which should be included in the system, find out the various needs of the academic staff in the E-Learning tools and reveal the level of expertise of the teaching staff in terms of E-Learning tools usage.

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# A Web-Based Recommendation System for Engineering Education E-Learning Systems

**Thorsten Sommer, Ursula Bach, Anja Richert and Sabina Jeschke**

**Abstract** Today there is a flood of e-learning and e-learning related solutions for engineering education. It is at least a time consuming task for a teacher to find an e-learning system, which matches their requirements. To assist teachers with this information overload, a web-based recommendation system for related e-learning solutions is under development to support teachers in the field of engineering education to find a matching e-learning system within minutes. Because the e-learning market is subject of very fast changes, an agile engineering process is used to ensure the capability to react on these changes. To solve the challenges of this project, an own user-flow visual programming language and an algorithm are under development. A special software stack is chosen to accelerate the development. Instead of classical back-office software to administer and maintain the project, a web-based approach is used – even for a complex editor. The determining of the necessary catalog of related solutions within "real-time" is based on big data technologies, data mining methods and statistically text analysis.

**Keywords** E-Learning · Recommendation System · Agile Process · Teachers · Professors · Web 2.0 · Software Engineering · Open Source

## 1 Introduction

To help teachers with their different challenges about finding an e-learning solution, a web-based recommendation system for e-learning systems is under development. This recommendation web-based service enables teachers to choose an engineering education e-learning system, which matches her or his requirements.

The term "e-learning" is often used in different matters. Therefore, this definition is chosen: "E-learning is an approach to teaching and learning, representing all or part of the educational model applied, that is based on the use of electronic media and devices as tools for improving access to training, communication and interaction and

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that facilitates the adoption of new ways of understanding and developing learning." [1] This definition includes any computer- and web-based tool, which is related to the education context.

A variety of e-learning systems and environments [2] are observable and the amount is continuous growing: From classical computer-based training (CBT), web-based training (WBT) [3], wikis and blogs [3], podcasts [4] respectively educasts [3] and game-based learning [3] up to massive open online courses (MOOC) [3, 5].

To illustrate the amount of related and available resources: A simple web-search for "e-learning" ends with over 1 billion results, a web-search for "e-learning system" with over 480 million results! Nearly 80 unique e-learning systems can be found in short time. This fact demonstrates the problem: The interested teacher must investigate this amount of information to find an e-learning system, which matches their personal requirements. Another problem is: The teacher might not be able to choose a system, which matches their requirements, because it is not trivial to understand all the technologies and differences between the unique systems.

## 2 Requirements and Challenges

The main precondition of the desired recommendation system is that the related e-learning systems are comparable. Moreover, a catalog of related solutions must exist. The approach to reach the comparable state is to find a set of necessary attributes that describes the characteristics of engineering education e-learning systems. These common e-learning characteristics must base on a broad scientific consensus: To realize this, the input of many experts is acquired.

The collected data about each e-learning system, together with the e-learning characteristics, results in a comparable data sheet about each e-learning system. This data sheet is subject of continuously changes to ensure that the data sheet is up-to-date and represents the current state of each system. Also the e-learning characteristics are subject of changes to cover all related kinds of e-learning.

The traditional approach to determine the catalog with the solutions uses a lot of resources (time, staff and money): Pay and get every e-learning system, prepare a server environment and install all systems. Then investigate the system (as teacher and student) and fill-up the data sheet. It is possible to speed-up this by using virtualization environments [6] like e. g. a type 1 hypervisor [7] with templates for the required environments, system snapshots and derivation between them.

The new and promising approach to determine the catalog with the available solutions is based on text mining: Crawling and parsing the public vendor and community information about the e-learning systems and store the raw data. Next, the raw text data is able to get analyzed to find out about the textual context. A half-automated algorithm suggests then a value for each characteristic, to assist the employee. Such a process is able to get executed e. g. every quarter to ensure that the data sheets are up-to-date.

To provide a convenient tool to develop and maintain the questionnaire, a new visual user-flow programming language is defined. This language is linking the catalog of solutions, the questions with further explanations for the teachers, the e-learning characteristics and the model of the user-flow together. Compared to existing survey solutions, the visual model and the deep integration are new.

Another challenge is that teachers expect a current, modern, responsive [8] and accessible user interface (UI). This is comprehensible, because it allows any teacher with any device and any handicap to use this web-based recommendation service. A responsive UI saves also time, because there is no need for an additional mobile and tablet websites [8]. Some web frameworks (e. g. Bootstrap[1]) assist the developer in these fields.

For further research (e. g. about e-learning systems and the teachers requirements to these systems), it would be helpful to collect some kind of key performance indicators (KPI) from the recommendation system. The data must be anonymous to keep the teachers privacy. Not only the end results must be logged, also e. g. the reaction time per question and – if present – the cancellation point etc. It is also interesting to capture all single decisions of any anonymous teacher to enable research e. g. in psychology fields.

## 3 User Flow Language

To enable the scientific assistants to model efficient the user-adapting questionnaire and to provide a convenient tool for maintaining the questionnaire, a new visual programming language [9] is defined.

The language is simple: Different squares – called "function blocks" – are connected by wires. For different purposes, different function blocks are present: Start, end, question, numeric and range blocks. Every function block has no or one input connector and no, one or three output connectors – this depends on the kind of the block. Behind every block, some data is stored: The reference to the common e-learning characteristic, a question, additional explanation text or just a text message – depends on the kind of the block.

Every program must have exact one start block, and at least one end block. The visual program must read from left to right: From the start block at the left, then follow block by block until reaches any of the end blocks. The concrete questionnaire can then deviated out of the visual program by simple traveling through the blocks. There is no special algorithm required to get or generate the questionnaire.

With this visual language, the visual program for the questionnaire has to be built. Explaining Fig. 1 as current example – to clarify the visual language: At the left, the start block was placed. The interviewee gets an introduction message to read. The flow is directed to "Question 1", a question block. The interviewee gets a question (the

[1] http://www.getbootstrap.com.

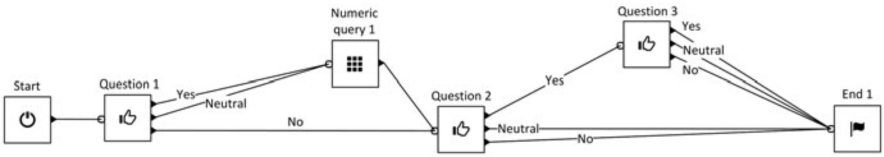


**Fig. 1** Example of the user flow visual programming language

question was defined before by a research assistant) and an additional explanation text. Related to the answer, the flow reaches "Numeric query 1" or "Question 2". The "Numeric query 1" prompts the teacher to answer a numeric question like e. g. "How many students are in your class?" From this block, the flow also reaches "Question 2". After "Question 2", the flow is able to reach "Question 3" or "End 1", related to the answer. "End 1" is also reached after answering "Question 3". At the end block, the interviewee is able to read a finished message. By pressing a button, the user submits all their answers to the algorithm.

Each question block has one input and three output connectors for the further flow: A yes-output, a no-output and a neutral-output. This corresponds to the possible answers of the interviewee. "Yes" means that the issue (subject of the question) must be present, "no" means the issue is not present or can be disabled and "neutral" means, that the issue does not matter.

A range block (this kind of block is not part of the example at Fig. 1) contains a text and an explanation text for the interviewee. To represent a range, this block needs two references to the corresponding parts of the common e-learning characteristics. This kind of block has one input and output connector.

While this project grows, the amount of different kind of function blocks will increased as necessary. For any new kind of block, also the algorithm (see Sect. 5) must be extended to cover the new functionality. New types of blocks are caused by changes at the common characteristics, to cover new requirements on the e-learning market.

For convenient usage, a simple web-based editor is under development. Thereby, it is possible to maintain the questionnaire without any programming skills. The whole life-cycle of the editor and the language is also convenient: There is no installation required, updates are only a server-side deployment and any kind of maintenance just occur on the server-side.

## 4 Engineering

### *4.1 Process*

To be able to react on new requirements on the whole process (software engineering, determining catalog of solutions, development at the algorithm etc.), agile best practices are chosen [10–12]:

- Use cases: Define a few use cases by drawing diagrams or by writing small so called “user stories” [10].
- Simplicity: Develop just necessary parts and leave anything which is not required [10, 12].
- Fast: Release fast and as many as possible to be able to get feedback from others [10, 12].
- Communication: Get early and continuously feedback from the customer, to ensure the project fits the requirements [10].

Additionally, not manageable challenges are divided into smaller – but manageable – challenges [10, 13]. It is also necessary to choose the right tool for right purpose: Do not use the same tool for anything – there are right purposes for any tool, but not all tools are convenient for all problems.

Even though different changes at the last 3 months, it was possible to reach the current state after just 8 weeks of work with just one person: This is perhaps related to the agile process. The process is promising for the further work and research.

## *4.2 Client-Side: Web-UI Approach*

At least two tools are required for the back-office: The editor for the visual language and the product editor. While the product editor is quite simple, the editor for the visual language is even more complex. Anyhow, a new approach is tested: Instead of developing the website for the teacher’s questionnaire and additional software for the back-office (with Java or .NET), anything will be developed as web-application.

For the web-application (for the back-office tools and also for the teacher’s questionnaire) just HTML5, CSS and JavaScript with Bootstrap[2] and jQuery[3] is used. Thereby, it is also useable on tablets like e. g. iPads – independently of the operating system. Further, also the final client performance is fine.

## *4.3 Server-Side: Software Stack*

On the server-side, a wide range of options are available. The best fit is a “BGMR stack”: FreeBSD[4], nginx[5], MongoDB[6] and Ruby[7]. FreeBSD [14] is very robust, secure, uses small resources and with the concept of “Jails” [15, 16] a powerful virtualization [6] environment is provided.

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[2] http://www.getbootstrap.com.
[3] http://www.jquery.com.
[4] http://www.freebsd.org.
[5] http://www.nginx.org.
[6] http://www.mongodb.org.
[7] https://www.ruby-lang.org.

The web-server nginx [17] is famous as powerful proxy, load-balancer and fasted server for static content [18]. Nginx delivers all necessary static data for this project (images, CSS, JavaScript, fonts etc.) But nginx is the wrong tool to deliver dynamic content, because the handling of external processes like e. g. the common PHP[8] is less efficient [18]. Therefore, non-static requests are passed-through to an application server.

MongoDB [19] is a robust, fast [20, 21] and scalable database. For the most Web 2.0 projects, MongoDB fits perfect, because the database is document-based and uses JSON [22]. If the project grows, the database is also able to scale.

Ruby is an object-oriented programming language [23] that provides a very convenient and fast way to develop web applications: On top of Ruby, the Sinatra[9] framework [24] provides an own web-centric DSL (domain-specific language). This enables a strong focus to web-oriented programming and reduced the necessary overhead a lot. While the project runs on the development environment with Ruby, for the production environment it is designated to run it with JRuby [25] on JavaEE with the JBoss application server [26].

This approach is very promising, because it speeds up the development, keeps the code clear – which makes the maintenance easier – and provides later with JRuby the power and scalability of JavaEE and the JBoss application server [25, 26].

## 5 Algorithm

To get the expected results out of the teacher's answers, an algorithm is under active development (see Figs. 2, 3, 4 and 5). The current state of the algorithm is constructed and validated with dedicated test data: As developing and testing environment, a normal spreadsheet application is chosen. A table with test data is representing the results of the questionnaire (the teacher's answers).

The term "issue" means in the context of the algorithm an element of the common e-learning characteristics, e. g. a product function, product behavior or a didactic method, but not a numeric or range question (see Sect. 3 for the differences). As input, the algorithm expects the static catalog of solutions as matrix: Horizontally the columns with the product issues, numeric questions and ranges etc. and vertically the rows with the products. The possible types of columns are corresponding to the available types of function blocks (see Sect. 3).

Out of the product point of view for the product data: Each issue can obtain the value $-100$ (the issue is not present), 1 (the issue is present and cannot be disabled) or 2 (the issue is present and can be disabled).

A range, e. g. the possible amount of students (from/to), is provided as two columns inside the matrix. Moreover, numeric fields are possible for e. g. the price,

[8] http://www.php.net.

[9] http://www.sinatrarb.com.

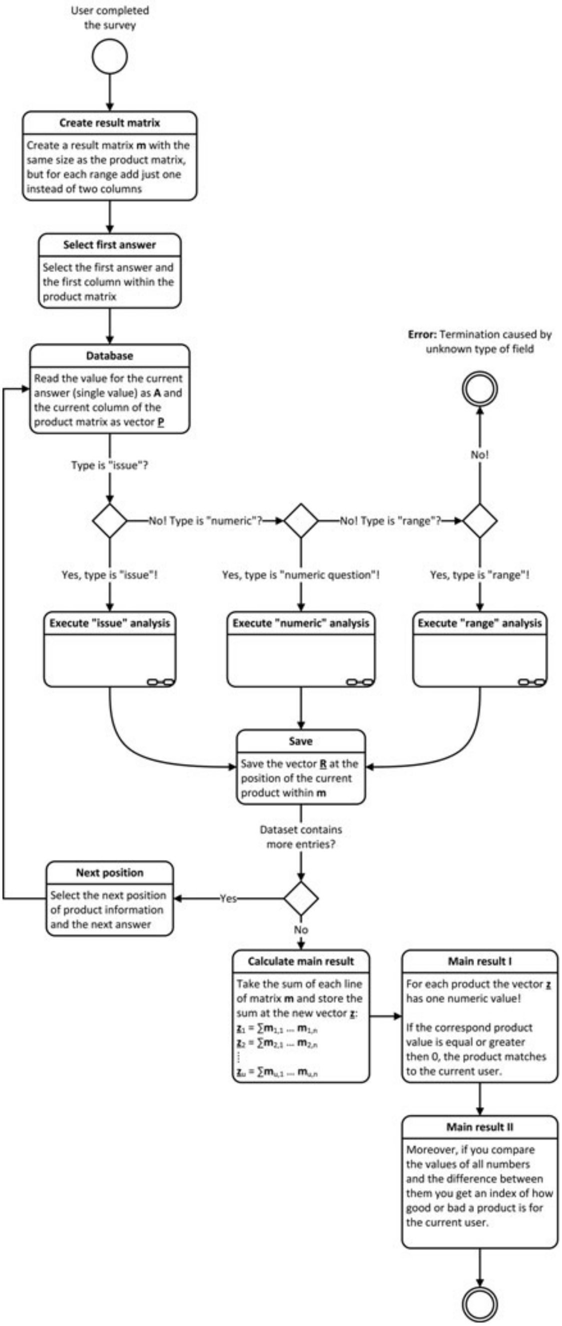



**Fig. 2** The recommendation algorithm to suggest e-learning systems

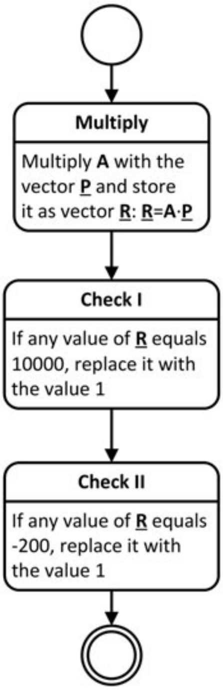



**Fig. 3** The sub-algorithm for the "issue" analysis

which are provided as one column inside the matrix. At the moment, numeric fields are able to hold only positive numbers (include 0).

Another input for the algorithm is the teacher's answers, provided as vector. Out of the teacher's point of view: Each issue can obtain the value −100 (issue is not present or can be disabled), 0 (issue does not matter) or 1 (issue must be present).

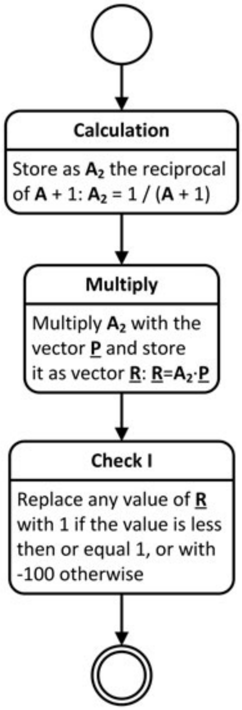
For each range, the answer can be a positive number (include 0) to represent e. g. the amount of students – or −100 if this does not matter. Finally for each numeric field, the answer can be a positive number (include 0) to represent e. g. the teacher's budget – or −100 if this does not matter.

The start point (see Fig. 5) is the end of the teacher's questionnaire. As first step, the result matrix **m** is created, with the same amount of rows as the product data and the nearly the same amount of columns (but for each range only one instead of two columns).

Important to know: The first question from the questionnaire corresponds to the first answer and this corresponds to the first column within the product matrix and also to the first column within **m**! Furthermore, a teacher receives might not all questions: The questionnaire is dynamic and user-adapting – the teacher gets only necessary questions. Any skipped question results implicit in the answer −100 which means "does not matter".

The next steps are repeated for each pair of an answer (the answer as a single value, here called **A**) and corresponding column out of the product matrix as vector $\underline{\mathbf{P}}$.

**Fig. 4** The sub-algorithm for the "numeric question" analysis




The algorithm is now branching out by the column type (for now: issue, numeric or range). If an unknown type of column is found, the algorithm gets unexpected terminated. The sub-algorithms for the different types are found at Fig. 3 (type is "issue"), Fig. 4 (type is "numeric question") and Fig. 5 (type is "range").

- In case of "issue", multiply $\mathbf{A}$ with $\underline{\mathbf{P}}$ and store the result as vector $\underline{\mathbf{R}}$: $\underline{\mathbf{R}} = \mathbf{A} \cdot \underline{\mathbf{P}}$. Check then, if any value of $\underline{\mathbf{R}}$ equals $10,000$. If so, replace it by 1. If any value of $\underline{\mathbf{R}}$ equals $-200$, replace it also with 1.
- If the type of the current column is "numeric question", store as $\mathbf{A}_2$ the reciprocal of $\mathbf{A} + 1$: $\mathbf{A}_2 = \frac{1}{\mathbf{A}+1}$. Now multiply $\mathbf{A}_2$ with $\underline{\mathbf{P}}$ and store the result as vector $\underline{\mathbf{R}}$: $\underline{\mathbf{R}} = \mathbf{A}_2 \cdot \underline{\mathbf{P}}$. Replace all values of $\underline{\mathbf{R}}$ with 1 if the value is less or equals 1 or otherwise replace it with $-100$.
- The "range" type is represented by two columns so instead of one $\underline{\mathbf{P}}$ this type has two vectors $\underline{\mathbf{P}}_{\text{min}}$ and $\underline{\mathbf{P}}_{\text{max}}$. If $\mathbf{A}$ equals $-100$, create the zero vector $\underline{\mathbf{R}}$ with the size of $\underline{\mathbf{P}}_{\text{min}}$ and this sub-algorithm is done. Otherwise, store as $\mathbf{A}_2$ the reciprocal of $\mathbf{A} + 1$: $\mathbf{A}_2 = \frac{1}{\mathbf{A}+1}$. Next, multiply $\mathbf{A}_2$ with $\underline{\mathbf{P}}_{\text{min}}$, $\underline{\mathbf{P}}_{\text{max}}$ and store the result as $\underline{\mathbf{R}}_{\text{min}}$ and $\underline{\mathbf{R}}_{\text{max}}$. Replace now any element of $\underline{\mathbf{R}}_{\text{min}}$ with 1 if the value is less or equals 1, otherwise replace it with $-100$. Also replace any element of $\underline{\mathbf{R}}_{\text{max}}$ with $-100$ if the value is less than 1, otherwise replace it with 1. The result vector $\underline{\mathbf{R}}$ is now $\underline{\mathbf{R}} = \underline{\mathbf{R}}_{\text{min}} + \underline{\mathbf{R}}_{\text{max}}$.

After the right sub-algorithm, the result vector $\underline{\mathbf{R}}$ must be stored at the corresponding position in $\mathbf{m}$. If not yet all pairs of answers and product data are executed, then select the next pair and repeat the steps above. If no pairs are left, take the sum of each line of matrix $\mathbf{m}$ and store the sum at the new vector $\underline{\mathbf{z}}$:

$$\begin{aligned} \mathbf{z}_1 &= \sum_{n=1}^{v} \mathbf{m}_{1,n} \\ \mathbf{z}_2 &= \sum_{n=1}^{v} \mathbf{m}_{2,n} \\ &\vdots \\ \mathbf{z}_u &= \sum_{n=1}^{v} \mathbf{m}_{u,n} \end{aligned} \tag{1}$$

$$\underline{\mathbf{z}} = \begin{pmatrix} \mathbf{z}_1 \\ \mathbf{z}_2 \\ \vdots \\ \mathbf{z}_u \end{pmatrix} \tag{2}$$

The variable $v$ starts at 1 and grows up to the amount of issues, numeric questions and two times the amount of range questions. The variable $u$ starts at 1 and grows up to the amount of products.

Interpretation of the results: The vector $\underline{\mathbf{z}}$ provides for each product one value. If a value is greater or equals 0, the corresponding product matches to the teacher's requirements. Moreover, if the resulting values are descending sorted, this new ordered list represents the teacher's best matching solution down to the worst solution[10].

## 6 Results

The chosen software stack has already proved its power: The development time has been short and the source code is clear, with less overhead and a strong focus to web development. Thereby, the first prototype is a responsive web solution: This saves time, because the mobile devices are covered without an additional mobile app. The agile process made it possible to react on changes to the subject of e-learning and also to common project changes.

[10] If the value is less than 0, the product is of course not a "solution" for this teacher.

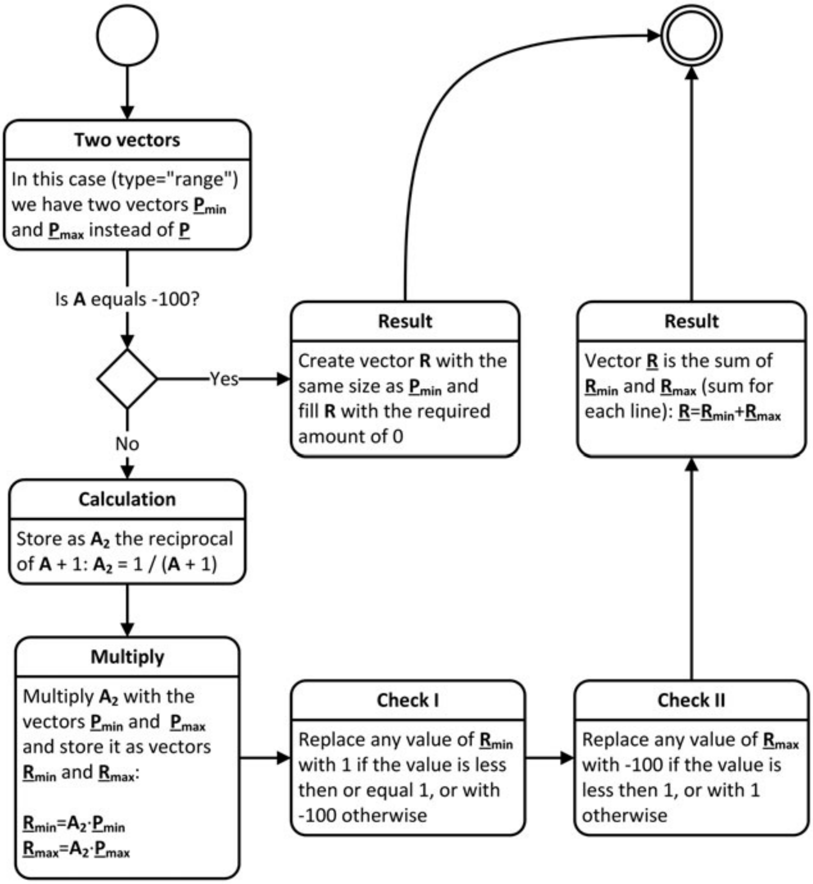



**Fig. 5** The sub-algorithm for the "range" analysis

The first technical prototype with the visual programming language and the questionnaire is running without errors: It is possible to write a visual program and test the user flow through the resulting questionnaire. It is possible to change the visual program while users are inside the user flow of the questionnaire: The users in front of the changed function blocks are receiving directly these changes, and users behind the changed blocks are not affected at all. This feature enables to run a long-term system with no or less maintenance impacts.

The visual web-based editor for creating a visual program is convenient and enables also staff without computer science knowledge to create a visual program. The first version of the algorithm is passing all test cases with dedicated test data: The algorithm is working deterministic and the results are correct for any expected input. In case of the comparable characteristics for the related e-learning solutions, which are the precondition for this recommendation system, a first proof of concept exists.

## 7 Conclusion and Outlook

To meet the precondition of comparable characteristics for related e-learning solutions it is promising to get the input of experts to reach a broad scientific consensus. Because it was possible to build a proof of concept for the characteristics, it is confident to meet this precondition. The recommendation algorithm needs further research to investigate the performance under real conditions with a huge solutions catalog and also huge amount of answers. Therefore, the algorithm must be implemented into the prototype.

The new visual user-flow language enables to build user-adapting questionnaires. This saves processing time for the teachers, because their get just the necessary parts of the whole questionnaire. Nevertheless: The user-flow program is able to cover the complexity from unexperienced to advanced teachers, regarding to the e-learning subject.

In the long-term view: If the web-based recommendation system goes online, the service enables teachers to save time and let them focus to the engineering education. Later, the recommendation system can be expanded to other disciplines, beyond engineering education. After the project reaches a more mature stage, it will be accessible as open source under the two-clause BSD license to enable others to use and modify it.

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# Chances and Risks of Using Clicker Software in XL Engineering Classes – from Theory to Practice

**Valerie Stehling, Ursula Bach, René Vossen and Sabina Jeschke**

**Abstract** Teaching and learning in XL-classes is a huge challenge to both lecturers as well as students. While lecturers face the difficulty of speaking to a mostly loud and very heterogenic audience, students often lack the opportunity of being an active participant in class. To counteract these difficulties and give the opportunity of immediate feedback, an audience response system has been introduced in the class of information technology in mechanical engineering at RWTH Aachen University.

In a previously published paper (Stehling, Valerie, Ursula Bach, Anja Richert, and Sabina Jeschke. 2012. Teaching professional knowledge to XL – classes with the help of digital technologies. *ProPEL Conference Proceedings*) the theoretical background has been outlined and presumptions have been drawn. The described redeployment of a lecture of the mentioned size was expected to bring about an enhancement of the quality in teaching of professional knowledge. It was also supposed to foster the often desired shift from teaching to learning. Now, after a first trial and evaluation of the method, these presumptions can be tested.

In this paper clicker questions from the lecture and their results are the groundwork that allow for a review of the evaluation of the first trial using clicker software in class. Results shall then allow for a comparison of the intended goals with the actual outcomes from the students' point of view. In addition to that, feedback and ideas for improvement through the evaluation of the "further comments" section by the "users" themselves can be gathered. The results of the analysis will then allow for an adjustment and improvement of the concept and may in the future give support to lecturers of other XL-classes that intend to implement an audience response system in their own lecture.

**Keywords** Large Classes · Clicker Software

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## 1 Initial Situation Outlines

RWTH Aachen University is a highly ranked university (see e. g. [1]) especially in the fields of engineering – mechanical engineering, electrical engineering, industrial engineering etc. It attracts a vast amount of students each semester which in the past has led to lecturers facing the challenge of having to teach a rising number of students each semester [2]. In the lecture "Information Management in Mechanical Engineering I" there are up to 2000 students each semester. This circumstance is partly a result of educational policy that subsequently reduces schooling from 13 to 12 years and thus leads to a vast increase in enrolment.

With such a large number of students it is impossible to give all of them the chance to actively take part in the lecture. Nor is it possible as in smaller seminars to get an idea of the knowledge background of your audience. Audience response systems (ARS) such as hardware clickers or in this case clicker software, however, offer the possibility to interact and thus get a chance of immediate feedback of the students even in large lectures. Therefore, the system was implemented and run in a first trial in the described lecture during the summer semester of 2012. At German universities the use of clicker systems or clicker software is not as widely spread as it is in other countries like e. g. the USA yet. Most clicker literature, however, only deals with implementing clicker systems in classes with up to a few hundred students. Therefore the technical process has been fostered and accompanied by researchers in didactics on the one hand and experts in information technology on the other. This interdisciplinary approach allowed for a multi-angle view on the implementation of the clicker software in anticipation of avoiding typical or common "beginner's mistakes" beforehand.

## 2 Intended Goals

The initial and main goal of the implementation of ARS in the lecture was to give students the chance to actively take part in the lecture instead of taking in all the information as a rather passive consumer. This is especially important when teaching a programming language[1]: just like with any other language you do not automatically learn by listening. It is the exercise that enhances the learning process. Another important goal as previously mentioned was to get an insight in the student learning and possible knowledge gaps. Based on immediate feedback made convenient by the use of modern technology it is possible to react near-term to difficulties in comprehension by repeating difficult subjects, starting a discussion about a controversial point or even changing the focus of the lecture. Rosenberg et al. point out further benefits of the implementation of ARS in class:

[1] The language taught in the described lecture is Java.

> Research has shown that students in courses using interactive engagement techniques ( . . . ) achieve a much greater gain in conceptual understanding than students in traditional lecture courses while also improving their ability to solve quantitative problems. [3]

Additionally, clicker questions are also known for their motivational benefits. "The questions are designed to motivate students and to unveil potential difficulties with the course topics and material." [4] As a positive 'side-effect', ARS offer the opportunity to connect learning with fun. "This approach has two benefits: It continuously actively engages the minds of the students, and it provides frequent and continuous feedback (to both the students and the instructor) about the level of understanding of the subject being discussed." [5]

## 3 Realization

While using ARS – especially hardware clickers – in class has been a common strategy for many years in countries like the USA, German universities have only discovered the benefits of these systems in the last few years. This means that the launch is expected to be 'virgin soil'. The launch has been carefully planned and realized by an interdisciplinary group of researchers in engineering, information technology and didactics. In a first step, possible questions were sought that matched the aims in teaching and learning of the lecturer. When looking for the appropriate application type, several can be chosen from. Here are some examples of purposes for which ARS can be used:

- Multiple-choice questioning
- Asking for computational results (numbers)
- Asking for coordinates (mark a point)
- Asking for Feedback by Multiple Choice (positive/negative)
- Asking for free text feedback
- Asking to enter questions
- Asking for free text answers
- Sequencing, etc.

Multiple-choice questions again offer several options of application:

- Choice of a right statement/answer
- Choice of a wrong statement/answer
- Choice of the right computational result, etc.

When integrating clicker questions in the topics of the lecture, it has to be considered that they take up a certain amount of time (questioning, polling, discussion) of the lecture – approximately three to five minutes each. So it is highly important to carefully plan when and on which topic they can be applied reasonably. Given the information that previous test results of the lecture have shown that the topic with the highest failure rate was coding, the clicker questions in this particular case were

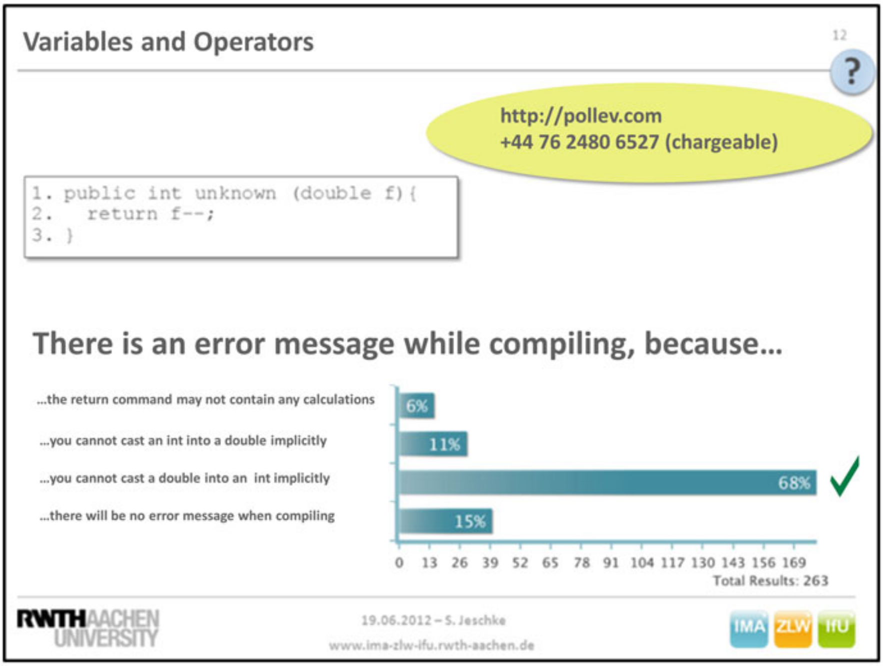


**Fig. 1** Screenshot of a clicker question with a clear tendency towards the right answer

designed specifically for the lectures covering this topic in order to detect difficulties in understanding early on.

Before using the software for the first serious clicker question, the lecturer shortly introduced the software during the lecture by a non-subject-related question. He also explained that the appearance of a question mark in the right hand corner of a slide signalizes a forthcoming question on one of the following slides. This element was chosen to keep the motivation and attention of the students at a high level. The first serious clicker questions were posed to keep track of the difficulties students might have when learning the basics of programming with Java. It was expected to be able to subsequently minimize these difficulties by discussing given answers. Figure 1 shows a screenshot of a clicker question slide and the response frequency in percent from the lecture.

In terms of the subject, the clicker question aims to check and foster the students' basic apprehension of the effects of operators. The question demonstrates decreasing a number variable using the postfix operator for and problems arising from implicit typecasting The slide shows a code. The question posed to the students is a multiple choice question of the right statement: "There is an error message while compiling, because . . ." The students can choose from four different answers that are supposed to detect the mistake in the code. While the majority (68 %) of the students answers the question correctly, 32 % give a wrong answer. With this result the lecturer can

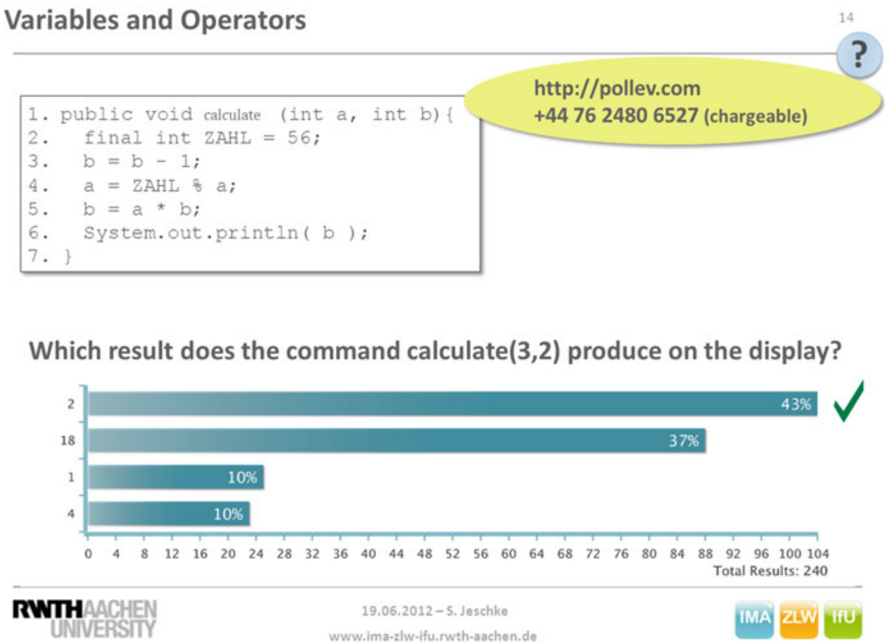


**Fig. 2** Screenshot of a clicker question with two very close tendencies, one of them indicating the right answer

seize the opportunity to explain, why the other options are incorrect to eliminate future mistakes.

Figure 2 shows a slightly different result.

On the second question slide the students see another code. This time, the question serves the purpose of showing the effects of different mathematical operators. The question posed to the students is: “Which result does the command calculate(3,2) produce on the display?” The question thus asks for a choice of the right computational result. The answers to this question appear not to have a clear tendency as in Fig. 1. This indicates that a majority of the students at this point of the lecture do not know the correct answer. This again gives the lecturer the opportunity to discuss and explain the answer. After the discussion and explanation a similar question but with a higher level of complexity is being posed to check possible learnings or difficulties of the students (Fig. 3).

The third question following shortly after the second one is another question of choice of the right computational result. Here, the workflow of a switch statement is demonstrated. The special focus lies on its behavior to execute all subsequent commands once a case has been matched. The question posed to the students is: “Which result does the command calculate(4,11) produce on the display?” The results show that 64 % of the students have chosen the wrong answer. Only 19 % of the students have answered the question correctly. After the display of the result, a

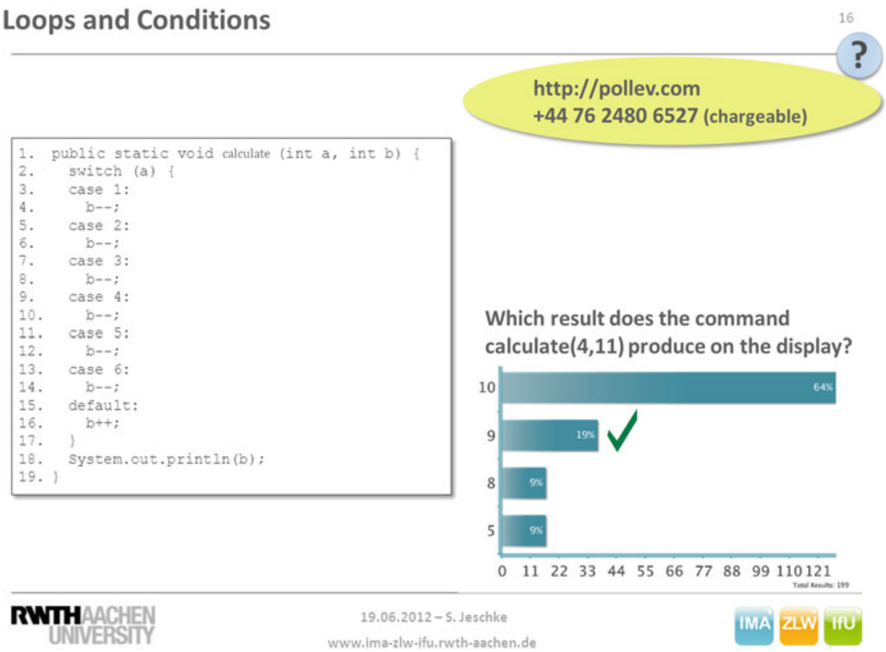


**Fig. 3** Screenshot of a clicker question with a clear tendency towards a wrong answer

positive and estimated side-effect was being observed by the teaching staff: subject-related discussions among the students began to evolve and the students tried to figure out why answer number 2 was the correct one. After that, the lecturer explained again and subsequently went on with the lecture. The following chapter shows and analyzes the results of the first evaluation of the trial implementation of 'poll everywhere' in the lecture by the students.

## 4 Results of First Evaluation

Worldwide evaluations at universities show that the application of ARS in lectures has led to e. g. higher motivation of attendance [6], more attention of the students during class and even higher knowledge acquisition than in conventional (non-interactive) classes. [7] After several trials the new ARS in the described setting was evaluated by the students near the end of the semester. The evaluation in this particular case was designed to cover the main topics motivation, usability and conceptual design of the questions. The evaluation on the RWTH Aachen University was carried out near the end of the semester, after several trials with the new ARS.

There are about 1800 ARS-related and filled-out evaluation sheets from the lecture. The questions posed were mostly closed-ended questions except for the comments

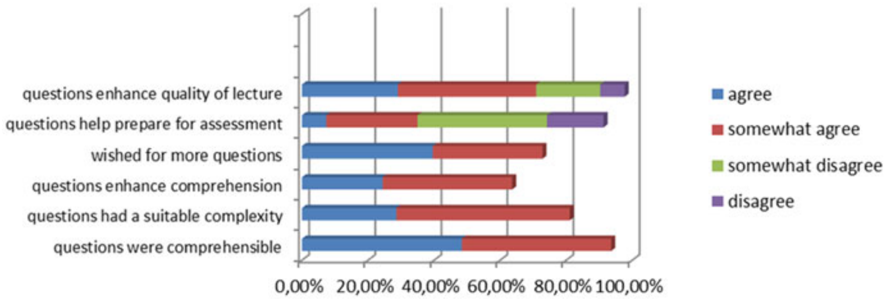


**Fig. 4** Results of the evaluation concerning aspects of comprehension and content

section at the end. They can be divided into several sections which included questions concerning:

- participation,
- impact on comprehension and content,
- motivational aspects,
- rating of the software itself and the methodological launch in the lecture.

The following sections will provide an insight into the most significant results of the evaluation. Every student (with an exception of two) who took part in the evaluation attended the particular lectures in which clicker questions were being posed. 60,3 % of the students actually used the software at least once to answer a question, 35 % of them participated in every single poll. Most of the students (43,3 %) used the software on their smartphone. 27,6 % did not participate at all because they did not have a smartphone or notebook (with them) and they probably did not want to spend extra money by sending a text message.

Figure 4 shows results of the evaluation concerning aspects of subject-related comprehension and content. A vast majority of the students (93,6 %) state that the questions were comprehensible and had a suitable complexity (81,1 %). Around 63 % say that the questions in class enhanced their comprehension which underlines the assumptions as drawn above: that posing adequate clicker questions and discussing right and wrong answers does not only activate students but can also foster and reveal their learning process. Nevertheless, a majority of 56,3 % also state that the questions did not help preparing for assessment. An especially positive outcome is that 70,9 % state that the questions enhance the quality of the lecture which leaves only 26,8 % stating that they don't.

Figure 5 shows the results concerning motivational aspects of the use of ARS in class. A majority (80,1 %) of the students enjoyed participating in polls. As has previously been found in other research, the clicker questions motivated a majority (79,7 %) of the students to be more attentive during the lecture. Only for 29 % of the students, however, see clicker questions as a motivating element for students to attend to the lecture at all. 68,7 % feel motivated to participate in the discussion of the subject and a similar number (69,6 %) state that ARS help feeling more involved

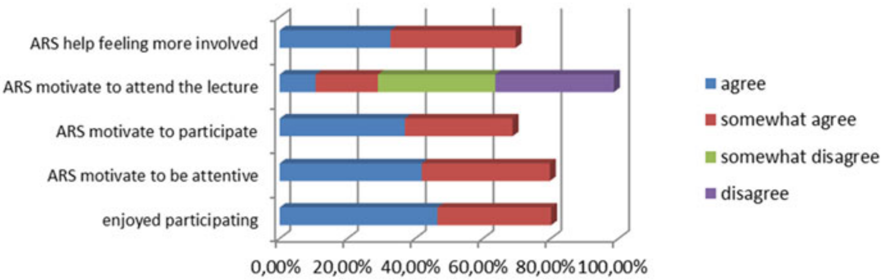


**Fig. 5** Results of the evaluation concerning motivational aspects

in the lecture. A total of 72,8 % even wish for more clicker questions throughout the semester.

Adjacent to the predominance of positive responses there also were some points of criticism. Most of these were related to the technical implementation given that the WiFi connection did not work well as soon as a lot of students wanted to participate at the same time. This explains why only a relatively small number of students participated in the polls with numbers around approximately 25 % of the students in the lecture per poll. Although most of the students thought dealing with the software itself was simple (84,4 %), some of them wished for a slightly longer answering period. Other students criticized real time tracking of the polls which has been used for some of the polls as they felt influenced by the already given answers of the other students.

In the comment section of the evaluation ten students specifically complimented the use of ARS. In addition to that there were also suggestions in which part of the lecture clicker questions should be used. Four students said that it would be better if clicker questions were used at the end of the lecture or at the end of a topic. Six students criticized that it was not possible for them to take part, because they had no smartphone or other device to participate.

## 5 Adjustments and Recommendations

The analysis of the evaluation has shown that most of the anticipated benefits of ARS (for further information see [2]) also apply when dealing with XL classes. Nevertheless, there was also criticism towards some important aspects such as the facility of participation – weak WiFi connection/lack of devices – and the methodology itself – presentation of poll results, frequency of questions, point of time etc. This criticism allows for several recommendations for future use adjustments to be made. The most preeminent points of criticism will here be discussed in terms of possible solutions. The largely positive reaction, however, allows for a recommendation of broadening of the use of ARS in very large classes.

## 5.1 Facility of Participation

The evaluation shows that the main reason for the relatively small number of participants can be ascribed to the weak WiFi connection. This problem can only be solved by the university. In order to avoid the frustration of not being able to participate, it is therefore highly important to address this problem to responsible university staff and give them the chance to improve the conditions.

The problem of participation without an own smartphone or laptop can be solved by having students team up in groups of up to a maximum of five students, each group having at least one functioning device to participate.

One decisive element regarding the software 'poll everywhere' is often underestimated by software designers: the integration of polls in the slides of the lecture – in this case power point slides. This feature allows for the lecturer to avoid discontinuities during the lecture and consequently avoids non-subject-related actions or breaks and the students could be distracted by. A change of the user interface, e. g., takes up time that students will most likely use to chat – and gaining back the attention of 2000 students once one has lost it can be very challenging. It is therefore recommended to choose software that provides the feature outlined above.

## 5.2 Methodology

The solution to the described criticism towards real-time tracking of the polls problem can be a simple one. The software allows for both methods of poll tracking – hidden as well as visible. Both methods have been tested in the trial. Both ways are plausible when linked to specific didactical goals. It is recommended to hide the development of the poll until an acceptable number of answers have been registered, close the poll and show the answers afterwards, unless a specific learning goal is being pursued. Showing the development of a poll in real time, however, can also be useful when e. g. linked to a certain didactical strategy such as peer instruction.

As has been previously stated, the sole implementation of an ARS in class cannot generate an improvement of a lecture – ideally, there is a didactical or conceptual goal behind every single question. Therefore, another suggestion is to combine clicker questions with successful didactical concepts such as just-in-time (JIT) teaching methods or e. g. peer instruction (PI).

> Just-in-Time Teaching (JiTT) is an ideal complement to PI, as JiTT structures students' reading before class and provides feedback so the instructor can tailor the PI questions to target student difficulties. [8]
>
> When PI is used, students are first asked to answer a question individually, and then a histogram of their responses may be displayed to the class. If there is substantial disagreement among responses, students are invited to discuss questions briefly with their neighbors and then revote before the correct answer is revealed. The instructor then displays the new histogram and explains the reasoning behind the correct answer. [9]

In the first ARS-trial of the described lecture solely multiple-choice questions were applied in order to check the apprehension of previously explained methods of e. g. programming or else explain it again. As Crouch et al. state there is, however, a possibility to use open ended questions in lectures with a lot of students:

> In a course with a large enrollment, it is often easiest for the instructor to poll for answers to multiple-choice questions. However, open-ended questions can also be posed using a variety of strategies. For example, the instructor can pose a question and ask students to write their answers in their notebooks. After giving students time to answer, the instructor lists several answer choices and asks students to select the choice that most closely corresponds to their own. Answer choices can be prepared ahead of time, or the instructor can identify common student answers by walking around the room while students are recording their answers and prepare a list in real time. [10]

Crouch et al. hereby describe one of unlimited options to pose open ended questions. This approach allows for a mix of approved didactical methods with new technology. Technology itself does not replace didactics or in Beatty's words: "Technology doesn't inherently improve learning" [11]. Only when choosing the 'right' strategy can a learning goal be achieved.

## 6 Future Prospects and Research Fields

The evaluation shows that using clicker software can be an efficient means to engage students – also in a very large class. Students in this particular class found the educational software to be motivating in terms of participation in class and helpful towards understanding. Nevertheless it is not a magic tool that automatically enhances motivation and learning. One result towards learning is that almost half of the students taking part in the evaluation somewhat agree that the questions in the lecture enhanced comprehension of the proposed subject, but did not specifically help when preparing for assessment. There was also the problem of participation – partly students were unable to participate in polls because they either did not own or bring a necessary device such as a phone or a laptop or the weak WiFi-connection did not allow for participation. It will therefore be a task for the second trial to on the one hand give the university the chance to improve the WiFi-connection while on the other to adapt methods that allow e. g. group participation to make sure every student can be involved. Many students wished for more clicker questions throughout the semester. As in the trial clicker questions were only posed in a few of the lectures, there is still latitude for extension.

The second trial shows the advantage of having more time – now that the technical implementation has been completed – to focus even more on subject-specific aspect of the clicker questions. One of the future prospects in the 'big picture' will furthermore be to use results of clicker questions in order to consequently detect knowledge gaps at an early stage. In terms of a holistic approach, the next step will then be to concurrently adapt the supplementary courses and exercises by focusing on these specific most challenging topics and most certainly to subsequently conduct further evaluations

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# Teaching Professional Knowledge to XL-Classes with the Help of Digital Technologies

**Valerie Stehling, Ursula Bach, Anja Richert and Sabina Jeschke**

**Abstract** How can the systematic use of digital technologies affect a lecture of 1500 or more students? Moreover, to what extent will it affect the learning outcomes of the students?

At RWTH Aachen University, subjects like Mechanical Engineering have to cope with a very high number of students each semester – currently the number lies at approximately 1500 with an estimated increase up to 2000 in the next semester. In order to create an interactive learning environment despite these difficult conditions, the IMA/ZLW&IfU (Institute of Information Management in Mechanical Engineering, Center for Learning and Knowledge Management and Assoc. Institute for Management Cybernetics) of the RWTH Aachen University is currently developing a pilot scheme that includes the application of Audience Response Systems in lectures with such large numbers of student listeners.

The implementation of the described system demands a redesign of the lecture with special regards to the content. Questions have to be developed that allow the students to interact with the lecturer as well as each other. This variety of questions ranges from multiple-choice questions to the inquiry of calculation results etc.

When giving students the chance to actively take part in a lecture of the described size by answering questions the lecturer asks with the help of technical equipment – which could in the easiest case be their own mobile phones – the lecturer creates a room for interaction. In addition to that he has the chance to get an immediate insight into the perceived knowledge of his or her students. This in turn enables the lecturer to react to obvious knowledge gaps that obstruct successful learning outcomes of the students. An additional benefit hoped for is that the attention of the students – which is a difficult issue for lecturers that face lectures with such a large number of students – might be kept at a higher level than average.

The described redeployment of a lecture of the mentioned size is expected to bring about an enhancement of the quality in teaching of professional knowledge. The presumptions made in this paper will be surveyed and thoroughly analysed during and after the realization of the project.

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## 1 Initial Situation

RWTH Aachen University is a highly ranked university especially in the fields of engineering – mechanical engineering, electrical engineering, industrial engineering etc. It therefore attracts a vast amount of students which in the past has lead lecturers to the challenge of having to teach a rising number of students in already large classes each semester (Fig. 1). This is even enforced by the German "G8" or "Gy8" concept which reduces studying in school from now 13 to then 12 years. In addition to that the conscription in Germany has been abolished which currently – but temporarily – leads to an even higher enforcement of increasing numbers of students. This means that by 2013 universities in NRW (Northrhine-Westfalia) will face an additional amount of student applications of around 275,000. Universities face not only the challenge of having to prepare themselves infrastructurally, the design of their lectures has to be customized as well.

## 2 Shifting from Teaching to Learning: A Special Challenge for Large Classes

With the previously pointed out development in mind: How can requested criteria of the Bologna Process like the "student centered approach" and an "emphasis on skills" – in other words a "shift from teaching to learning" be considered when

**Fig. 1** Large class at RWTH Aachen University. (Source: http://www.taz.de/!86786/)

planning a lecture with more than 1000 listeners? It is, this has to be said in advance, neither our aim nor any given possibility to split the large lectures into small groups. Lectures in the classical sense serve the purpose of conveying scientific findings and general content that the students need to be able to transform this knowledge into practice in specially designed laboratory or exercise courses. However, current research shows that motivation and attention of students during a classical ex-cathedra lecture decreases drastically already in early stages of the lecture [1].

First outcomes of a current monitoring survey by the ZLW conducted in classes of the engineering sciences show that at RWTH Aachen University most large lectures still have their focus on the teaching aspect rather than promote learning: Students are often passive consumers of knowledge. This of course only goes for the lecture itself – most of these classes have additional exercise courses or labs in which the students get the chance to work together on a subject in small groups. Previous research however shows that one way to gain a certain level of learning in a lecture is to give the students the chance to learn actively – not only in these additional exercise courses but also in the lecture itself [2]. Davis e. g. states that students learn best when they are active participants in the education process [3, 4]. Of course, when talking of lecture sizes beyond a seminar size, this task is a special challenge to every lecturer [5, 6].

Some of the aspects making active learning in a large class a special challenge can be summed up as the following:

- Speaking in front of a large class is often frightening for students. They might compromise themselves when giving a wrong answer.
- Large classes are loud. The level of noise can quickly become very high once the attention of the students starts to diminish. When answering a question in a large class the answer is often overheard because it is too loud in class.
- Even when the lecturer frequently asks questions in his or her class, he or she still cannot involve all the students at the same time [5, 7].

However, finding a solution to this challenge is not that simple. At the IMA/ZLW&IfU, several projects currently deal with the advancement of teaching and learning to an excellent level taking on both perspectives – the teaching perspective as well as the learning perspective (e. g. "ELLI" – Excellence in Teaching and Learning in the Engineering Sciences; "ExAcT" – Center of Excellence in Academic Teaching – for more information see:http://www.ima-zlw-ifu.rwth-aachen.de/en/research/aktuelle_projekte).

TeachINGLearnING.EU (http://www.teaching-learning.eu), a project dealing with teaching and learning concepts especially in the engineering sciences funded by the "Stiftung Mercator" and the "Volkswagen Foundation" and also conducted by (amongst others) the ZLW has – as one of its goals – set up competitions in an "open innovation"-approach. These competitions give students the chance of influencing the learning environments and settings the university offers them. One of these competitions has covered the subject of large class management and how it can be improved. Thirty-one ideas were handed in by students and ten of the proposed ideas concerned the lack of interaction between teachers and students during or after class. Some of these proposals suggested the use of technology to help overcome fears of speaking due to the size of the class or even admitting that one did not understand the subject matter the lecturer has just explained. Findings of Andersen et al. affirm this appraisal. In their pilot study 6 out of 12 students state that in large classes they feel apprehensive of participating [5]. Proposed ideas in the competition mentioned above range from the "IDIOT (I DId nOt get iT)-Buzzers" to classic Audience Response Systems. These offer the possibility to either (in the first case) be able to press a button when a student feels that something has not been explained thoroughly enough or to (in the second case) send questions to the teaching assistant during class that he can either immediately react to in the following lecture.

## 3 Response Systems – A Possible Teaching Method for XL-Classes?

The described ideas suggested by students show that coherent to current research results and requests for a change in didactics addressed towards university teachers there is a demand for active learning and interaction in class. According to modern age students or in Prensky's words "digital natives" [8], (new) technologies e. g. in the form of Response Systems can be a means to improve the learning outcomes of students.

Jeschke in this context talks about the potential of new media in education [9]. Prensky even states that "our students have changed radically" and that "today's students are no longer the people our educational system was designed to teach" [8]. And this statement leads us to the same conclusion Ketteridge comes to: That "change in education is inevitable as institutions invent and reinvent themselves over time and space" [10].

Using classroom communication systems (CCS) is not a recent innovation – the first popular CCS "Classtalk" was developed in 1985. Writing about the appropriate application, the benefits and downsides of using CCS in class is therefore neither a brand new issue. Of course, since 1985, Response Systems have been improved and advanced as have digital technologies in general. However most research on this topic up to now is dealing with CCS or RS in classes with up to approximately 500 students – so regarding the particular aspect of the as previously described XL-sized classes is definitely interesting.

Evaluations of best practices from universities worldwide show that the application of Response Systems (RS) in lectures has led to e. g. higher motivation of attendance [11], more attention of the students during class [1] and even higher knowledge acquisition than in conventional (non-interactive) classes [1]. According to Sellar RSs "( . . . ) have been found to be of particular benefit when working with large groups where communication is challenging ( . . . )" [12]. It will be very interesting to see whether this will become evident in classes with up to 2000 students as well.

## 4 Use of Technology Equals Learning?

"Technology doesn't inherently improve learning" [13]. This proposition stated by Beatty does not come out of the blue: Some teachers might be thrilled by the new technology in their classroom but do not use it properly and efficiently due to a lack of pedagogical or didactical conceptualization. Kerres also states that digital media are no "Trojan horses" that can be brought into an organization (or situation such as a class) and unfold their effect "overnight" [14]. Kay and LeSage reinforce these statements by stating that "( . . . ) the integration of an ARS into a classroom does not guarantee improved student learning" but that "it is the implementation of pedagogical strategies in combination with the technology that ultimately influences student success" [15].

According to Kerres [16] universities need for an individual media strategy that ensures an appropriate use and a successful outcome of innovations in teaching by new media. This strategy should at least cover four topics of change:

- Reform of teaching: Which (new) contents of teaching do we want to convey? Reform of teaching methods: Which (new) methods of teaching and learning do we aim for?
- Production of media supported learning environments (inclusive the development of a didactical concept and (if necessary) the development of media) as well as the distribution of the media.
- Designing the personnel and structural conditions for the successful usage of media (HR measures).
- Extension and backup of the infrastructure (hard- and software, installment, attendance, fosterage) [16].

The following section will deal with the first two of Kerres' as well as other topics, which are especially relevant for this particular paper.

## 5 Conceptual Design

There are many best practices to look at when redesigning a lecture to give an appropriate room for the use of Audience Response Systems (ARS) possible. Considering the fact that most of these best practices will have to cope with much less students than RWTH Aachen University, a creative solution needs to be found to ensure that the benefits of the Response System become effective.

The conceptual design of the implementation of a clicker system in the lecture of information technology in the engineering education at RWTH Aachen University with currently approximately 1500 students will be described in the following subsections.

Every lecture is unique due to its specific content, so there is no prototype solution for a conceptual design when introducing RS into large classes. Neither can the conceptual design described in the following sections act as a prototype solution.

Along with the first two topics Kerres [16] sees as indispensable, a few other items need to be considered when planning to introduce Response Systems in this particular large class.

1. Reform of teaching: new contents; methods of teaching and learning
2. Production of media supported learning environments; distribution of the media
3. Financing
4. Motivation for using clickers – student/lecturer approach
5. Roll-Out, Evaluation and Adjustments

These topics will in the following be discussed against the background of the implementation of a Response System in the previously described lecture "Information technology in mechanical engineering" teaching approximately 2000 students.

## *5.1 Reform of Teaching – Contents and Methods*

When planning to introduce a Response System in a lecture, it has to be considered that clicker questions take up a certain amount of time of the lecture. The content of the original lecture thus has to be adjusted to this. And the more clicker questions you as a lecturer ask, the more time for the usual content you will have to give up. According to Beatty, this is a step in the right direction:

> An instructor cannot and should not explicitly address in class every topic, idea, fact, term, and procedure for which students are "responsible". Instead, use class time to build a solid understanding of core concepts, and let pre-class reading and post-class homework provide the rest. [13]

It is not conducive, however, to overload a lecture with clicker questions and turn it into a quizzing lecture. Clicker questions need to be carefully planned and placed. Beatty et al. state that "classroom response systems can be powerful tools ( . . . ). Their efficacy strongly depends on the quality of the questions" [17]. Crews et al. also state that using clickers in the same way every lecture can become monotonous to the students and therefore become counterproductive. "Instructors should be prepared to implement clickers for different purposes throughout the semester ( . . . )" [3]. Examples named here are discussions (pre-, during and post-), quizzes, competitions between groups, student generated questions etc. [3].

Several types of questioning seem appropriate and conducive for the described lecture in the engineering sciences. For example: Since the lecture deals with (amongst other subjects) programming and basics of software engineering it surely is interesting and helpful for further planning processes to get to know your audience better. This can for example be achieved by asking the students in the first lecture which computer languages they already know. Additionally it can be a benefit to ask multiple choice questions and later discuss the answers given. Beatty states that the focus when "quizzing" the audience should not lie on the correctness of the answers but on the reasoning behind it [13]. He also appeals to the right responses when right or wrong answers are given: "How we respond when right or wrong answers are given is crucial. A full spectrum of answers should be drawn out and discussed before we give any indication which (if any) is correct [13].” One very important element here is the “wow factor”: By arranging questions cleverly, making mistakes can create an opportunity to learn and considering that mistakes are made anonymously and possibly by a lot of other students too it might therefore lose its negative connotations in class.

Considering that at RWTH Aachen University the use of clickers in class is not a common and well-known teaching method (neither to the students nor to the lecturers), the changes in teaching should not be rushed. Teachers and students need a certain amount of time to learn their “new role” [13] in the lecture: Participants of a more interactive, student-centered approach [2]. This might additionally cause an initial “fear” or “discomfort” on both ends. Especially students might react negatively in the beginning: while the teacher has already had a chance to accustom to his new role in the planning process, students begin with this process at the beginning of the first lecture. Usually, before they see the actual benefits for themselves like a better learning outcome or understanding, they see the “downsides”: they need to prepare before the lecture in order to “perform well” in these mini-tests which they might think is the purpose of using Response Systems [13].

On the other hand, lecturers in the described class at RWTH Aachen University will benefit from an expectable rather positive attitude of the students towards technology anchored in their own choice to study mechanical engineering. This is an additional benefit to the assumption that young students today can be described as digital natives or in terms of Wim Veen: “Homo zappiens” [18]. Considering these aspects, we can assume that using this new technology in class will feel natural and intuitional to the students and the playful element [18] participating will have a strong motivational effect on them.

Summing up it is necessary when designing contents and methods for a teaching approach using Response Systems it is highly important to keep a sharp eye on pedagogical as well as learning goals. According to Beatty these learning or pedagogical goals include

- drawing out students’ background knowledge and beliefs on a topic,
- making students aware of their own and others’ perceptions of a situation,
- discovering points of confusion or misconception,
- distinguishing two related concepts,
- realizing parallels or connections between different ideas,
- elaborating the understanding of a concept,
- exploring the implications of an idea in a new or extended context [13].

These pedagogical goals should be achieved by using the playful element of clickers in the lecture and promoting learning as something that can be fun, too.


**Fig. 2** Poll Everywhere in use at the MIT. (Source: http://polleverywhere.com/how-it-works)

### *5.2 Production of Media*

For the lecture, a simple and accessible software is being rented to ensure a very high access rate. The software, "Poll Everywhere" is designed in a way that every student owning any mobile phone, wifi-device or laptop can participate (Fig. 2). The screenshot (Fig. 3) shows the three steps it takes to start a poll in class.

When you as a lecturer design a poll, you first have to choose which sort of poll you want to use: You can either ask a multiple choice question or let the audience answer a question freely with any text reply (see Fig. 4). If you have decided to ask a multiple choice question, you can type in the question and the possible answers and set the options for participation (see Fig. 5).

Having finished this you can show the students your question and the possible answers including the possible ways of participation (see Fig. 6). Those students who do not own a smart phone or wifi-device but own a simple mobile phone that supports text-messaging can easily participate by texting their answer to a displayed phone number.

For those students owning neither a wifi-device nor a simple mobile phone, there still is the possibility of actively contributing to the answer by grouping together with their fellow students and discuss a possible answer. This would also serve a positive side effect of enhancing subject-related discussions between students. Once having opened a poll you can then watch the votes rise in real time as they are received. So in the classic sense of a Class or Audience Response System, this technology

- allows an instructor to present a question or problem to the class,
- allows students to enter their answers into their devices (mobile phones, laptops etc.) and
- instantly aggregates and summarizes students' answers for the instructor [13].


**Fig. 3** Screenshot 1: How it works. (Source: http://www.polleverywhere.com/#how-it-works)


**Fig. 4** How to create a new poll [12]

The essential advantage of this software compared to other Response Systems is that students do not have to buy special hardware and accordingly the university does not have to provide devices in class which would be a huge financial burden when lecturing classes of thousands of students. Students are not charged for voting on

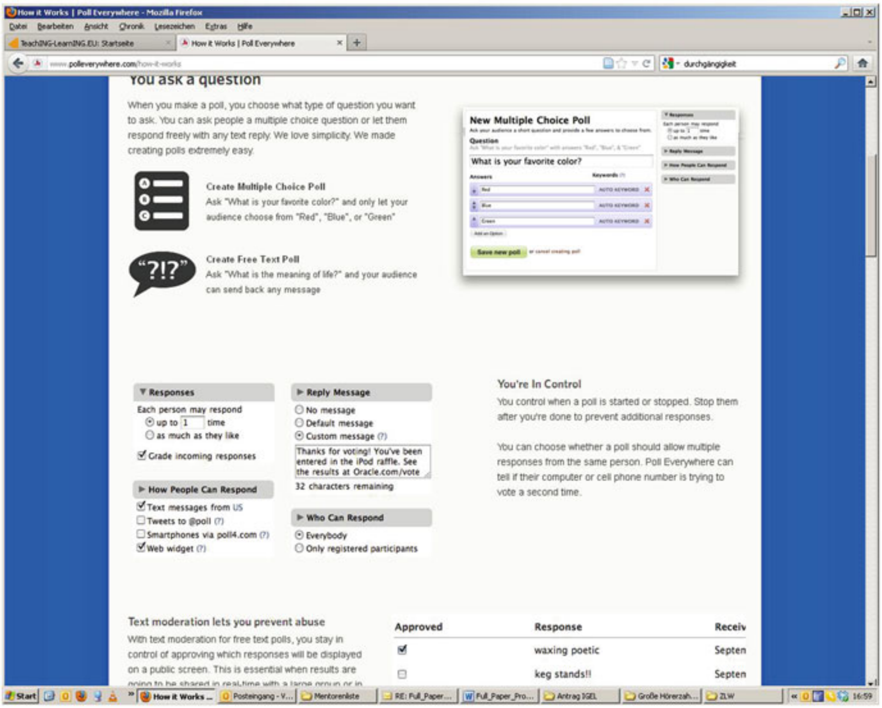


**Fig. 5** Installing a poll via Poll Everywhere. (Source: http://www.polleverywhere.com/how-it-works)

Poll Everywhere; however, if they vote by text message then standard text messaging charges apply [12].

## 5.3 *Financing*

By introducing a Response System into a lecture the person responsible for the organization and content of the lecture has to make several expenditures. It will cost time, effort and – of course – money. Usually the lecturer, the institution or the faculty has to pay for the software or application. In the described case the fees are according to class or audience sizes. The bigger expenditure is the amount of time (in terms of staff costs) to adjust or redesign the lecture to the application of clicker questions. As previously described clicker questions need to be carefully designed and should always be strongly tied to a specific learning goal. Current research shows that this is one of the most challenging tasks when introducing clickers into any class and therefore takes up most of the preparation time.

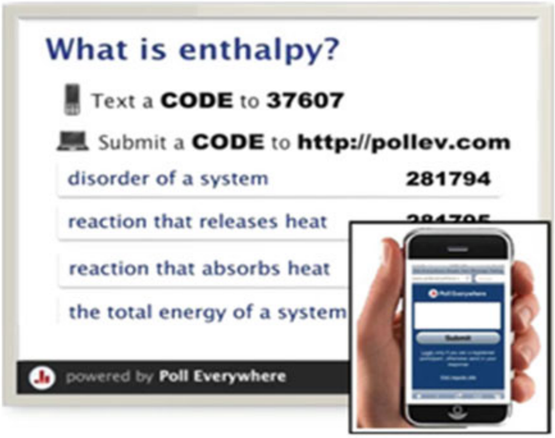


**Fig. 6** Example of a poll. (Source: http://dukedigitalinitiative.duke.edu/wp-content/uploads/2011/08/pollEverywhere.jpg)

One advantage of poll everywhere is that due to technical development no clicker hardware or device has to be bought neither by students nor by the university. This is a huge financial improvement – especially in large classes – which also has an impact on student participation in online polls in class – students easily forget to bring their clicker devices to class, because they only use it for class, but the probability of students forgetting to bring their mobile phones is rather small.

At RWTH Aachen University and especially the Faculty of Mechanical Engineering the commitment to advance new concepts in teaching and learning is extraordinarily high. Projects like "The "Students in Focus" Future Strategy" (http://www.rwth-aachen.de/go/id/bbtb) as well as previously described projects like "ELLI", "TeachING-LearnING.EU", "ExAcT" etc. currently put a lot of time and effort into finding and establishing innovative teaching designs. Additional funding for the described careful preparation of the desired implementation this paper deals with has been raised in a special "Exploratory Teaching Space"-Call named "IGEL" (Interactive Large Classes for Excellent Teaching) to enhance excellence in teaching (http://www.cil.rwth-aachen.de/tag/exzellente-lehre/).

## *5.4 Motivation*

Clicker Systems or the implementation of such into a lecture (as every other change process) is as has been pointed out always conjoined by at least financial and temporal aspects. Therefore, the positive aspects of the redesign have to prevail to build up a motivation to take these "burdens" upon oneself (oneself being the lecturer, the institution, faculty or even university). These positive aspects or advantages should be predominant for the lecturer as well as for the students. If you want a Response System to fulfill its "purpose" and increase interactivity by "promoting a two-way-flow of communication between the speaker and the audience" [12], both ends need

**Table 1** Benefits of clickers for the student versus benefits of clickers for the lecturer

| Benefits of clickers for the student | Benefits of clickers for the lecturer |
|---|---|
| Interaction with the lecturer without fear of compromising oneself | Identification of knowledge gaps |
| Immediate feedback | Identification of shortcomings of the lecture [7] |
| Possibility to actively check their learning outcomes outside of exams | Student engagement |
| Be an active participant in class | Keeps students focused and involved |
| Anonymity | Higher attendance |
| Enhancement of learning | Better control of the learning progress |
| Classroom experience more enjoyable | ... |
| ... | |

**Table 2** Disadvantages of clickers for the student versus disadvantages of clickers for the lecturer

| Disadvantages of clickers for the student | Disadvantages of clickers for the lecturer |
|---|---|
| Equipment/software functionning | Clicker questions take up time pre and during class |
| Equipment accessibility | The implementation itself costs time and money |
| Costs occurring when only option of contributing for the student is a text message | Equipment/software functionning |
| ... | Diversion by using technical devices in class |
| | ... |

to be "on board". To point out that an implementation of the described Response System is worth all the cost and effort, the following graphs will sum up the most advantages and disadvantages found by review of literature in the field of Response Systems. These are separated into benefits and disadvantages for the teacher on the one hand and the student on the other (Tables 1 and 2).

Evaluations of lectures that are already working with RS in class show a few challenges and downsides aroused by the introduction of RS. These will be summed up in the following chart. It is noticeable, though, that there are a lot more positive aspects on either– the student as well as the teacher – side.

One argument that has not been mentioned in this paper before but is often discussed is that students are or might be diverted [1] by using their technical devices – mobile phones, laptops etc. – in class is not steady. One of the results of the monitoring survey conducted in large classes of engineering sciences described earlier in this paper is that most students use their phones or laptops during class for texting and social networks anyway – so why should a lecturer not take advantage of this and use it for educational purposes?

### 5.5 Roll-Out, Evaluation and Adjustments

Since the lecture in which the Response System is going to be introduced is held in the second semester of the engineering sciences and therefore only takes place in the summer term, the research on this topic is still in progress. First clicker questions will be introduced from the first lecture date of the summer semester 2012.

To secure and check the outcomes of the implementation of a system that enhances a new teaching and learning approach in "XL"-classes and whether previously found results from other universities can be acknowledged, the implementation must be concomitantly evaluated. First evaluations are planned for the middle of the summer semester 2012 – during the pilot study – by questioning both the students and the lecturer to get a first insight on the perception of the new approach. A conclusive and detailed evaluation will follow at the end of the semester.

Considering that all lectures at RWTH Aachen University are being evaluated by the students each semester, we expect to see changes in this evaluation so we can come up with a first rating whether the approach also works for groups of the described size or not.

Results of the evaluations and perceived outcomes (acceptance, estimated learning outcomes, participation, attention etc.) from the pilot study will be published as well.

## 6 Limitations and Future Prospects

Due to the fact that the paper deals with research still in progress we cannot yet give any valid recommendations or report learnings from the implementation process. These findings will as previously mentioned be published later.

However, by conducting this accompanying study, we expect to find out by analyzing the evaluation sheets whether Response Systems are an appropriate means for advancing interaction and subsequently enhancing student learning and attention in class. The benefits and disadvantages collocated by reviewing previous literature as well as simple estimations in this paper will be revised for the special case of "XL"-classes according to the findings in our evaluations.

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# Challanges of Large Group Study Courses in Engineering Education

**Janine Stieger, Anne-Carina Thelen, Ursula Bach, Anja Richert and Sabina Jeschke**

**Abstract** Teaching in front of large audiences (> 700 students) is a challenge to every lecturer. Because of the rising shortage of skilled workers particularly in engineering education new ways to provide high-quality education while at the same time allowing for large audiences need to be designed. An essential way to improve engineering education is seen in the "shift from teaching to learning", i. e from teacher-centered to student-centered education. A possible strategy of student-centered learning is "project-based learning" which facilitates action-oriented and sustainable learning. Although it is a big challenge, project-based learning can also be successfully used in large group study courses. Besides a description of central challenges when dealing with large audiences the article points out the importance of didactically innovative and student-centered forms of teaching and learning for engineering education. Furthermore, the article sketches project-based learning as a form of student-centered learning and gives a case study of the course "Communication and Organizational Development" at RWTH Aachen University.

**Keywords** Large Group Study Courses · Engineering Education · Project-Based Learning

## 1 Introduction

With continuously increasing numbers of students and at the same time shrinking funds, lecturers are confronted with large audiences (> 700 students) more than ever before. How can the subject matter of mass events be conveyed to the individual student and be understandable for everyone? What forms of interaction are appropriate? How does the subject matter catch on with the individual students? These are some of the questions that teachers of a huge audience have to find answers to.

Since more than one decade the notion "shift from teaching to learning" [1] has been used for expressing the change from a teacher-centered to a student-centered

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view of learning. This paper presents the shift from teaching to learning and its central characteristics. Constitutive challenges of teaching large group study courses as well as the particular situation in engineering education are described, especially shadowed against the background of student-centered learning. In lectures with high numbers of students the application of active and student-centered learning is demanding and goes along with new responsibilities for lecturers. Especially in engineering education, the situation of large audiences is made worse by the shortage of skilled workers caused by demographic factors. Therefore it is a decisive factor to reduce the quota of university drop-outs in engineering science and to improve the quality of teaching.

Furthermore, this paper presents project-based learning as one possible strategy of student-centered learning. Project-based learning starts out from a problem that students have to solve on their own through team work. This course of action fosters both professional and supra-professional skills. Finally, the course "Communication and Organizational Development" at RWTH University is presented as one example of employing project-based learning in engineering education with large audiences. In a lecture-complementary practice session some 1200 students pass through a process of organizational development where they team up to found a fictional automotive enterprise and build the prototype of an innovative automobile.

## 2 Shift from Teaching to Learning

In the course of the Bologna Process that was started in 1999 by 30 European states a paradigm change in teaching and studying has been initiated for the European university landscape. One central idea of the paradigm change is to entirely rethink university teaching from the perspective of student learning [1]. Affected by the 1995 article of Robert B. Barr and John Tagg "Shift from Teaching to Learning – A New Paradigm for Undergraduate Education", the expression "from teaching to learning" has become the leading motif of a new quality of studying and learning that stands for a new view on teaching [2].

From the viewpoint of university didactics the shift "from teaching to learning" is about replacing the traditional, rather presentational and instructional paradigm of university teaching by a notion of teaching that understands itself as fostering of student learning. Besides the basic change of perspective that tries to design teaching from the student viewpoint this approach encompasses the requirement that students carry a central responsibility within the learning process [3]. The shift from teaching to learning looks at the learning results and at the strategies used to reach them [4].

One major prerequisite for the success of student-centered learning is that the teachers attend the learning process as a coach [1]. Learning processes can be described as a triangle relationship between teachers, students and the topic. In didactic theoretical tradition this is depicted by the didactic triangle according to Heger [5] (cf. Fig. 1). Thereby, the triangle relationship can be designed in a variety of ways.

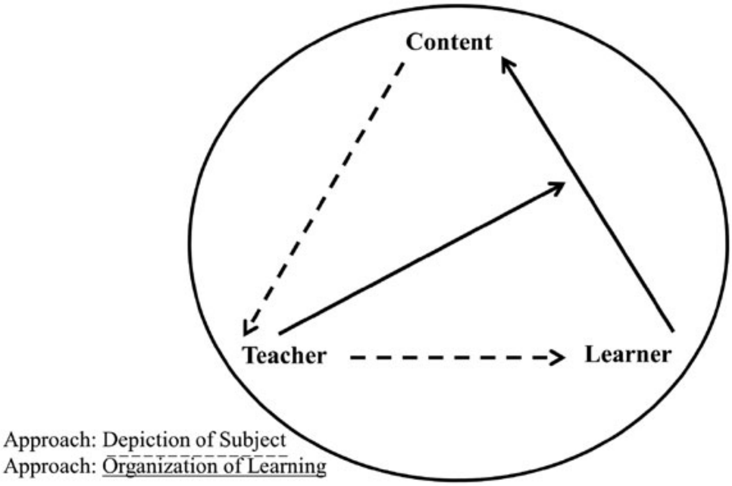


**Fig. 1** Didactic triangle [6], according to Heger [5]

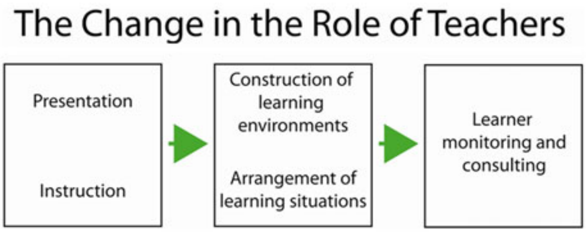


**Fig. 2** Change in the role of teachers according to Wildt [4]

Hitherto existing university teaching is often still affected by a classic role constellation expressed e. g. in lecturing [2] the teachers are tasked with processing content, they fabricate knowledge and transport it to the learners, as pointed out by the two broken lines starting from content via the teacher to the learner (cf. Fig. 1). In the student-centered notion of university teaching, however, the learner stands in direct interaction with the content while the teacher helps to organize this process. Figure 1 depicts this with the continuous lines.

Barr and Tagg [1] expressed the change from a teacher-centered to a student-centered view as a move from the "Instruction Paradigm" in which teachers deliver instructions to transfer knowledge from faculty to student to a "Learning Paradigm" in which universities produce learning [7]. According to that the shift from teaching to learning contains a change of roles of the teachers from their tasks of presentation and instruction via the construction of learning environments to accompaniment of learning where they aid and counsel students (cf. Fig. 2).

According to Wildt [3] the change of view from teaching to learning can finally be described by the following characteristics:

- student-centered approach,
- change of the role of teacher away from the orientation towards instruction,
- orientation of learning towards goals and results,
- fostering of self-organized and active learning,
- consideration of motivational and social aspects of learning,
- linking of knowledge acquisition and acquisition of learning strategies.

With the shift from teaching to learning teaching is elaborated from the viewpoint of the student and the central role of the teacher is to enable a learning environment where students can actively develop their knowledge instead of having it conveyed only passively.

## 3 Teaching Large Group Study Courses

### 3.1 Central Challenges

With the rising number of high school graduates university courses with large group study courses are not unusual. With constantly shrinking funds, a lot of lecturers have to face larger classes in order to make up for the lack of faculty members with regard to the growing number of students [8]. Particularly in mass fields of study courses can have 700 to over 1000 participants [9].

The leader among the applied forms of university courses to address large numbers of students is the head-on tuition, i. e the classical lecture. But the effort of teaching large classes by lecturing has not to be underestimated. Both lecturers as well as students face a number of physical and psychological problems that have to be solved. Thus, it is not enough for a professor to just talk louder, write bigger and make larger gestures. While lecturing, teachers stand in front of an undifferentiated mass and often cannot even recognize faces in the back of the room. Students on the other side feel faceless and suffer from anonymity.

Traditional lectures are hardly adequate to allow for [10]. In the context of a mere listener, the student has a passive role and receives the information transmitted from the lecturer.

Nevertheless, against the clear disadvantages of large group lectures, because of the rising number of students, they will be inevitable in the future. For improving the study situation, it is rather about generating an expansion of the didactic action repertoire where the teachers create new learning environments that can be used to supplement lectures [4].

### 3.2 The Stituation in Engineering Education

Ninety-three percent of the lecturers in mechanical and electrical engineering bachelor degree programs state that they use the classical lecture format [11]. A dependable

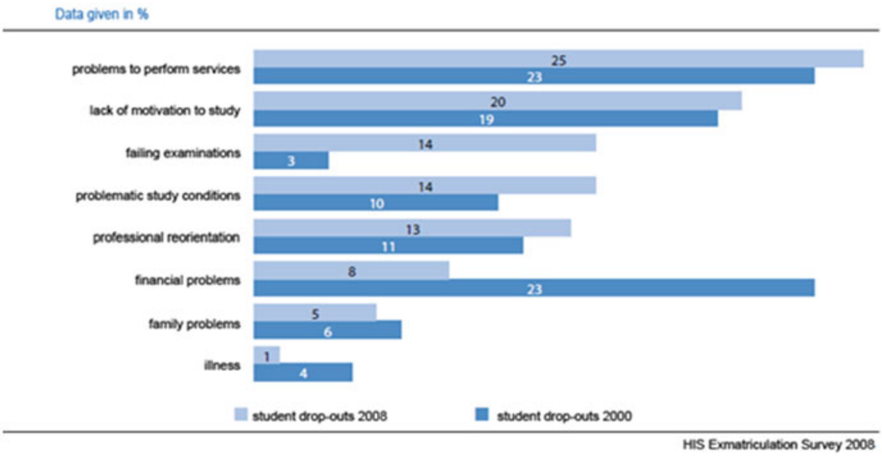


**Fig. 3** Crucial dropout reasons: subject group engineering at universities [12]

instrument to investigate how students cope with a given study situation and large classes is the dropout rate. A study from the Higher Education Information System (HIS) gives information about the dropout rates of different subject groups and the motives students stated when breaking off their studies [12]. It shows that of all the students who enrolled in engineering sciences between 1999 and 2001, 25 % left university without a degree. With 25 % the most crucial reason for students breaking off studying in 2008 is their problem to perform services, followed by the lack of motivation to study with 20 % (cf. Fig. 3).

As the study shows, also failing in examinations (14 %), problematic study conditions (14 %) as well as professional reorientation (13 %) are mentioned as central reasons for breaking off. As deficient study situation criteria the HIS study (cf. [12, p. 18]) refers to

- confusing courses of study,
- overcrowded courses,
- lack of relevance and practice,
- insufficient study organization,
- lack of professional standards for the courses,
- lack of mentoring by lecturers,
- anonymity at the university,
- scarce university equipment.

Concerning the professional reorientation students declare the wish for a more practical education as the main reason for breaking off (cf. [12, p. 39]). Their expectations of studying engineering science were not fulfilled as they probably were not informed enough when choosing the field of study.

Given the global lack of competent professional engineers, the number of engineering students leaving university without a degree is alarming. According to the outlook of the Cologne Institute for Economic Research (IW) in cooperation with The Association of German Engineers (VDI) there are not enough young graduates to replace the engineers who retire. By the year 2014 the German economy will eventually lack around 220,000 engineers, scientists and technicians whereas only an average of 37,000 engineers graduate each year [13]. Therefore, the high dropout quote in engineering studies must be cut and as many students as possible must be qualitatively educated at the same time.

The research of approaches that enhance teaching and learning under the condition of large audiences is a substantial task of the competence center for engineering education TeachING-LearnING.EU. As a cooperative project of RWTH Aachen University, the Ruhr University Bochum and the Technical University Dortmund, TeachING-LearnING.EU pursues the goal of sustainably improving the quality of engineering degree programs in the context of the Bologna Process. Project research has displayed that one successful teaching method for student-centered learning is project-based learning.

## 4 Project-Based Learning

Till today, many different approaches have been developed to teaching that fit the criteria for student-centered learning. One effective form of student-centered learning is project-based learning. In project-based learning students are confronted with a complex project that has to be collaboratively accomplished based on the learnt theoretical knowledge. While instructors or tutors take on the role as coaches and facilitators of learning, the learners are self-responsible for the most part of their activity and encouraged to take responsibility for their group and mission. In project-based learning the learning activities are organized around achieving a shared goal by project work. The instructor of project-based learning mediates specifications to reach the goal of the project and with the role as a facilitator controls the compliance with the correct proceeding [14].

As Savery [14] merges, learners are likely to encounter several problems by working on their project. At this, feedback and reflection on the learning process and group dynamics are essential components: periodical group-feedbacks in connection with working-units help learners to reflect their functioning and appreciate the outcome. The different teaching methods are adapted to respective learning targets, learner knowledge and context of the project as well as practical application, so that learners are able to memorize experiences that will serve them in future situations (cf. [14]).

Project-based learning is a distinguished example for student-centered and active learning and advances effectively the acquirement of professional skills and abilities. Moylan [15] identifies the skills that students learn with project-based learning as

- critical thinking and problem solving,
- creativity and innovation,
- collaboration, teamwork, and leadership,
- cross-cultural understanding,

- communications and information fluency,
- computing and information & communication technology fluency,
- career and learning self-reliance. [15]

For this reason, since the 1970s project-based learning continues to grow in popularity worldwide and is getting more and more common in engineering education, too. Although lecture-supplementary study courses and project-based learning are not a new occurrence in university teaching, they are still a central challenge especially for courses with large audiences. Despite of the didactical and organizational challenges the course "Communication and Organizational Development" at the RWTH Aachen University illustrates the implementation of project-based learning in a large group study course.

## 5 Project-Based Learning in Engineering Education

One example of dealing with large audiences by project-based learning is the course "Communication and Organizational Development" at RWTH University Aachen. The Department of Information Management in Mechanical Engineering and the Center for Learning and Knowledge Management (IMA/ZLW) at the RWTH University of Aachen successfully implements the concept of project-based learning in the "Communication and Organizational Development Lab" despite the high number of participants.

The Communication and Organizational Development Lab is scheduled for the first semester in the bachelor-degree course of mechanical engineering and takes place in the form of two mass events with up to 1400 students overall. The lab features practical application and testing of the previously gathered theoretical knowledge. During the 2-day lab the students undergo an organizational development process: in groups of 25 they start a fictional company with various departments in the automobile industry, set goals, develop corporate strategies and build a prototype of an innovative soapbox. Led by the simulation, the students' actions reflect on their team and they need to build requirements for a successful teamwork. Good logistics (25 areas with identical equipment) and strictly following the schedule are essential for the successful completion of the project.

The students are responsible for their group achievements, tutors interfere as little as possible. After a short theoretical introduction into communicational and organizational theory, students have to solve the problems with their own knowledge. The tasks are defined in a way that challenges the students to solve them within the predefined period of time. Thus, the students have to work with the little information that is given and understand that their theoretical knowledge helps them complete their tasks.

With the help of different exercises and activities the participants prepare presentations, which they later present in the plenum. In this way key competence like presentation, creative techniques and problem solving behavior in the work process are conveyed. Each group is supervised by two tutors from the Department of Information Management in Mechanical Engineering and the Center for Learning and Knowledge Management (IMA/ZLW). Self-reflection sessions are carried through after each work step and at the end of the course. Participating in the Communication and Organizational Development Lab students actively develop valuable professional skills by coping with realistic problems and solutions and are encouraged to take responsibility for their own learning.

## 6 Conclusion

Despite the disadvantages of lectures with high numbers of students, large group study courses will be unavoidable in tertiary education. Still, the fundamental change in university didactics toward a student-centered perspective does not mean that traditional functions of "frontal" teaching and receptive learning will not retain an important significance at universities. In fact, to improve the study situation it is rather about generating an expansion of the didactic action repertoire where teachers create new learning environments beyond classical lectures. These learning environments then can be successfully used to supplement lectures and to allow for active learning of the students. Given the rising shortage of skilled workers especially in engineering, the quality of teaching has to be improved in order to reduce the high drop-out rates.

As presented in this paper, project-based learning is one effective form of student-centered learning that provides a variety of professional skills and abilities needed in the twenty-first century workplace. It empowers learners to integrate theory and practice, to apply theoretical knowledge and thus provides them with professional skills. However, it is still a big challenge to implement project-based learning also in large group study courses. The case study of the course Communication and Organizational Development for engineering students illustrates, though, that even with large group study courses the application of project-based learning is possible.

As a central future task for higher education research further innovative concepts have to be developed that shape the change from a teacher- to a student-centered perspective. Concepts of student-centered learning such as project-based learning have to be adjusted to fit large group study courses. Appropriate concepts for study courses in engineering science have to be enhanced/improved and tested in practice. This task is significant if nothing else to assure the connectivity of scientific education to entrepreneurial and social practice.

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# A Knowledge Map Tool for Supporting Learning in Information Science

**Helmut Vieritz, Hans-Christian Schmitz, Effie Lai-Chon Law, Maren Scheffel, Daniel Schilberg and Sabina Jeschke**

**Abstract** Large classes at universities (> 1600 students) create their own challenges for teaching and learning. Audience feedback is lacking and fine tuning of lectures, courses and exam preparation to address individual needs is very difficult to achieve. At RWTH Aachen University, a course concept and a knowledge map learning tool aimed to support individual students to prepare for exams in information science through theme-based exercises were developed and evaluated. The tool was grounded in the notion of self-regulated learning with the goal of enabling students to learn independently.

**Keywords** Knowledge Map · Large Classes · Self-Regulated Learning · Higher Education · Information Science

## 1 Introduction

The Institute of Information Management in Mechanical Engineering (IMA) of the RWTH Aachen University (RWTH) offers a lecture about information science in mechanical engineering (see Fig. 1) that is combined with a lab, a group exercise and exam preparation courses. The lecture focuses on object-oriented software development and software engineering (more details in [1]). In a previous semester more than 1600 students attended the lecture. It received good evaluations from students as well as staff. This feedback was taken into account to revise the lecture, the lab and the courses a little further for the summer term of 2012. Here are some of the

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**Fig. 1** Lecture for information science in mechanical engineering ©David Emanuel

challenging questions of the revision: a) How can the student's learning process be supported in a better way? b) What are the main obstacles the students face when learning programming concepts and techniques of object-oriented programming and software engineering? c) Which resources are needed to improve the learning process and are these available? d) How can student-by-student communication be used for peer instruction to relieve the tutors?

The e-learning system L2P[1] of the RWTH is already widely used as a Learning Management System (LMS) in the lecture, the group exercises and the lab. However, additional learning support was requested to assist students in and out of class, but particularly when learning autonomously. Therefore, a Web-based e-learning test bed was designed and implemented which supports different kind of learning situations as autonomous learning, peer-instruction learning as well as e-mail support by tutors. It extended the L2P learning room with interactive and autonomous learning capabilities.

Additionally, a tool test bed evaluation was designed to analyse how the test bed impacts the students' learning processes. Some research questions addressed were: a) Are the students willing to use interactive e-learning tools? b) Is the students' feedback to the teaching staff supported by the test bed, e. g. regarding learning interests and obstacles? c) Is the test bed capable to support students and tutors in the

[1] http://www2.elearning.rwth-aachen.de/english.

**Fig. 2** Schedule of lecture, group exercise and lab during the summer term 2012

| Week | Lecture | Lab | Group Exercise |
|---|---|---|---|
| 1 | Java Basics | | |
| 2 | | Java Basics | Java Basics |
| 3 | Object-oriented Programming | | Object-oriented Programming |
| 4 | | Intro NXT | |
| 5 | | NXT Sensors | |
| 6 | | | |
| 7 | | NXT Actors | |
| 8 | Software Engineering | | Software Engineering |
| 9 | | Final Exercise | |
| 10 | | | |
| 11 | | | |

learning and teaching process? d) How can the additional challenges of large classes (user management, anonymity etc.) be managed within the test bed?

The rest of the paper is structured as follows: Sect. 2 will describe the general course design. In Sect. 3, related research is discussed, followed by an explanation of the self-regulated learning concept. Then, the ROLE environment will be introduced (Sect. 4). Finally, in Sect. 5 we will present the evaluation and conclude in Sect. 6.

## 2 Course Concept

The lecture period of the summer semester 2012 started in April and ended in July, followed by a time of exam preparation courses starting in September. The time between these two blocks was used for autonomous, self-regulated learning (SRL). The environment for individual exam preparation was implemented consisting of three ROLE (Responsive Open Learning Environments) widgets, namely a knowledge map, a chat widget and a history widget. In the lab students were able to experiment and actively apply the fundamentals of object-oriented programming with Java. It took place together with the lecture during the summer term from April to July (see Fig. 2). The exam preparation courses in September offer the students the possibility to train the addressed competences in smaller audiences.

In addition to renewing the lecture format, the course organisation was updated and supplementary digital material was provided to the students via the RWTH learning management system L2P. The course's L2P was then enhanced by a selection of ROLE[2] widgets, more specifically by widgets supporting self-regulated learning (SRL). Furthermore, another Technology Enhanced Learning (TEL) aspect was introduced into the course by adding a Personal Response System (PRS) – sometimes also described as an Audience Response System (ARS). This TEL tool complemented the ROLE technology as it enhanced the opportunity of further active

[2] http://http://www.role-project.eu/.

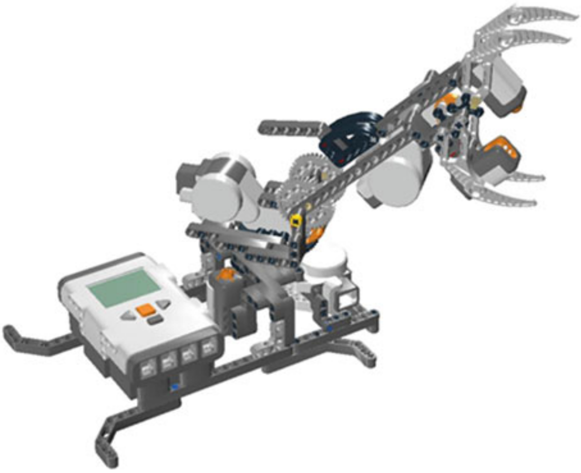

**Fig. 3** Model of the LEGO Mindstorms NXT robot used in the laboratory [1]

learning prospects for students and also offered an increased interactive setting in terms of the pedagogical delivery.

Previous student evaluations had shown a demand for more self-contained programming occasions as well as practical "hands-on" tasks to try out. The newly designed lab sessions thus offered palpable tasks that the students could carry out completely on their own. The setup for these object-oriented programming lessons was based on working with LEGO Mindstorms NXT (see Fig. 3) robots for use by large classes. To support the Java programming language implementation on the NXT controller, LeJOS was used [2].

The RWTH ROLE test bed work in 2012 was initiated with a Web-based survey that aimed to collect details about the students experience with e-learning and SRL at the beginning of the lab in April 2012. The ROLE widget environment was introduced to the students during the second week of their studies. The enriched ROLE-based learning environment offered additional support for improvement in SRL opportunities. It also provided particular information about programming in general, related tools, modelling, as well as Java itself. Around 1600 students participated in the course. All students were informed about the ROLE-enhanced learning environment offer via several announcements during lectures and labs and via email. During the standard midterm teaching evaluation, a short ROLE-related survey was issued. At the end of the lecture period, the ROLE test bed was also adapted for individual exam preparation during summer time. Finally, after the exam educational staff was interviewed to evaluate the environment and its application within the course.

The lab sessions took place in the largest computer pool of the RWTH which is equipped with approximately 200 workstations. This, however, restricted the maximum number of students that could attend the lab in parallel to 200 students who then worked with 100 Mindstorms NXT robots. Since those 100 robots could not be dismounted and reassembled in each lesson, the lab was based on a standardised and pre-assembled robot model as depicted in Fig. 3. This allowed for several student teams to work with the same robot set in consecutive classes and improved the comparability of the students' achievements. (To increase motivation, it would have been desirable that each team had their dedicated construction set. However, this would have resulted in an order of 750 robot construction kits.)

The second part of the lab sessions was based on the principle of problem-based learning. The students were requested to program a robotic gripper inspired by industrial robots. This resemblance to "real" robots was meant to result in a better understanding of mechanical engineering principles by the students. The assigned task was to get the robot to scan their surrounding area for coloured balls, picking them up and putting them into a box. In order to get the robots to detect the balls, students could make use of an ultrasonic sensor, a light sensor and a touch sensor located within the gripper. The robot arm could be moved up and down as well as left and right by directly controlling the corresponding motors. The third motor controlled the gripper hand. The students implemented this task during the remainder of the lab. To allow for progress tracking and giving weaker students a chance to catch up, the overall goal was separated into four sections as described below.

## 3 Related Research and Self-Regulated Learning

The presented approach addresses different recent research issues such as teaching and learning in large classes as well as using cloud services and Web 2.0 applications for e-learning support. The challenge of teaching large classes has been a research issues for many years (cf. [3, 4]). The more technical background of building e-learning tools from Web 2.0 components is being discussed in [5]. The approach uses six dimensions for the mapping of Web 2.0 applications to personalised learning environments. The capabilities of ROLE-based cloud learning services are investigated in [6]. The evaluation shows that cloud-based learning support with ROLE environments is possible but the learners may need introduction and time to be familiar with interactive e-learning tools. The particular aspect of navigation guidance for learning questions in Java programming is discussed in [7].

Self-regulated learning (SRL) denotes a learning process where the learner herself decides what to learn, when and how [8]. Different scholars have attempted to develop SRL models such as the five-component SRL model of [9], which comprises cognition, meta-cognition, motivation, affects, and volition.

SRL is a central pedagogical focus for higher education in general and the project ROLE in particular. SRL empowers the learners to manage their own learning irrespective of organisational interventions. According to [10], the quality of learning outcomes varies with the extent to which learners are capable of regulating their own learning. In addition, SRL is considered a core competency for a professional career because of several reasons. Firstly, to keep abreast with the rapid social and technical development of a dynamic society requires life-long learning skills, which entail high autonomy. Secondly, the border between working and learning is getting blurred: we learn while we work by resolving issues in the workplace and we work

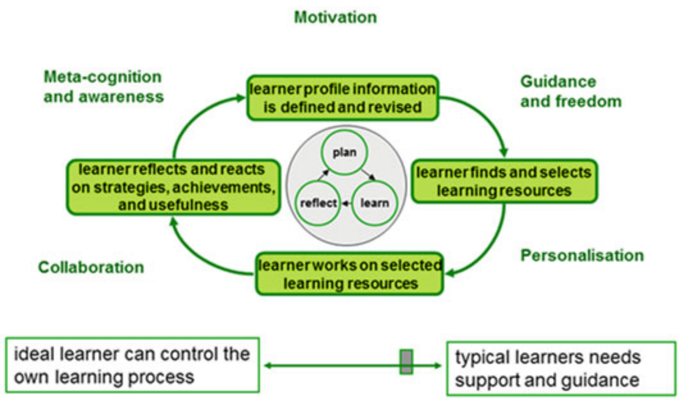


**Fig. 4** The SRL concept [11]

while we learn by directly applying what we have learnt; SRL skills enable us to integrate seamlessly the knowledge and experience from both realms. Thirdly, it has been shown that self-regulation improves learning outcomes [10].

Nonetheless, the advantages of SRL can only be realised provided the learner is able to follow a SRL approach. Self-regulation manifestation is a continuum rather than all-or-none. It ranges from an entirely independent pursuit for knowledge and skills to a structured coaching with a teacher working alongside with a learner. In the latter, it could be challenging for both teachers and learners. Amongst others, some salient issues include: learners are not accustomed to deciding learning goals for themselves and thus need some even highly structured guidance; teachers might not be prepared to give freedom to learners while they are still held responsible for their learning progress; organisations might not be prepared to engage learners and teachers in learning scenarios that are relatively open, rendering accreditation or any kind of formal assessment of learning outcomes difficult.

Specifically, in ROLE, the SRL process model is defined as a learner-centric cyclic model consisting of four recurring learning phases (see Fig. 4): i) learner profile information is defined or revised; ii) learner finds and selects learning resources; iii) learner works on selected learning resources; and iv) learner reflects and reacts on strategies, achievements and usefulness [11].

To enable the fulfilment of these learning phases, a learning environment and sets of learning activities should be provided where learners can practice how to learn in a self-regulated manner. The aforementioned learning environment can provide additional learning material (knowledge map) that can be browsed independently, provide help by lecturers and tutors, provide communication channels to exchange with others. That is, support plan and learn. Evaluating the extent to which the students acquire the SRL skills in this way can effectively be measured through a well-designed survey.

## 4 The Online Learning Environment

In the test bed there are three ROLE widgets: the Web 2.0 Knowledge Map widget (WKM, [12], see Fig. 4), the chat widget and the history widget. The test bed scenario was deployed for the lab and also for the individual exam preparation of the students in August and September.

The WKM aimed to provide the students with information covered in the lecture and the lab. It was filled with additional SRL-adapted content thus focusing on typical SRL situations such as the exam preparation phase. It contained explanations and motivations for notions, definitions or examples, e. g. for basic Java programming constructs. Background information, e. g. about the installation and usage of the Eclipse programming environment, was provided as well. Exercises for exam preparation were associated with content. These entities of content are called knowledge objects. The presentation and organisation of the WKM followed the paradigm of object-oriented analyses and design in software development. Relations between objects and classes of objects were visualised (see Fig. 5) to underline knowledge associations. Functionalities for annotations, remarks and feedback were provided to support individual SRL. For the first time in the course's history, the WKM gave students an opportunity for individual support during their time of exam preparation.

The second widget, a chat widget, was embedded to offer students the possibility to ask and answer topic-related questions. Other students answered the posed questions and, additionally, a tutor also moderated the chat. Finally, a history widget was embedded into the learning environment. It supported the backward navigation within the environment by offering the last five activated knowledge objects. Based on inter-widget communication (IWC, [13]), the widget used data from the WKM widget to support the learner with his or her own learning history. The WKM was maintained by the IMA, the test bed was hosted by the department of information science at the RWTH and access to the WKM was granted via the login for the lab.

## 5 Evaluation

The ROLE environment was used to some extent during the lab time from April to June. Usage has grown significantly some weeks before the exam in September when the students started their individual preparation. Additionally, the existence and purpose of the learning tools were announced by an email to all students. The access peak was reached in the days just before the exam when students switched to "power learning". This is illustrated by Fig. 6 showing the number (by day) of accessed knowledge objects. A knowledge object is a small piece of content as a notion explanation or an exercise. Figure 6 thus underlines the exam-oriented learning during the exam preparation that restricts the leeway in learning and thus the autonomy of the learner. The e-learning environment consisting of knowledge-map, history and chat enables independent and cooperative learning. Moreover, it

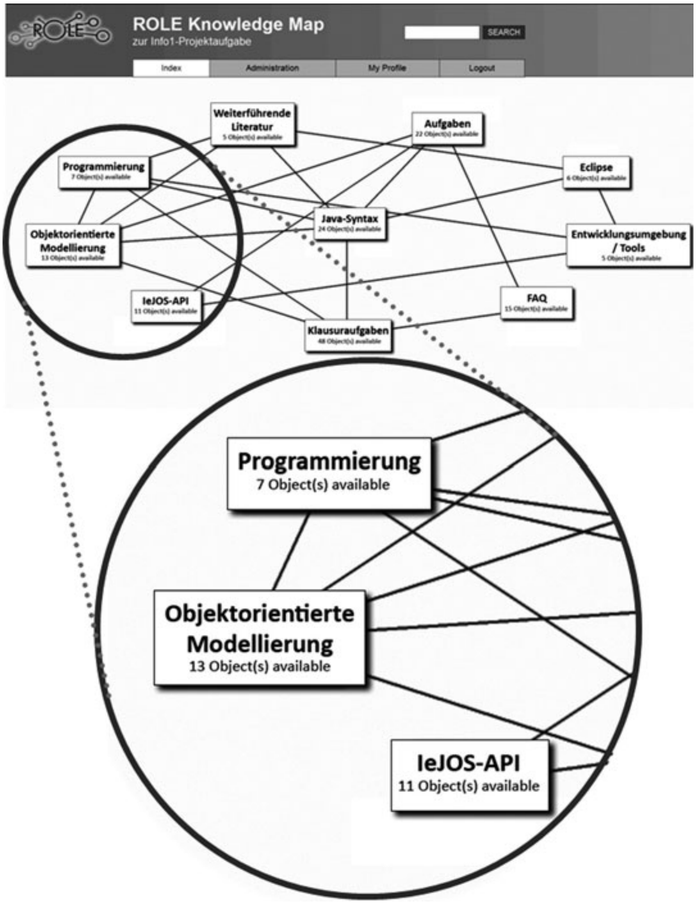


**Fig. 5** Screenshot of the RWTH WKM (start page)

offers learning flexibility since the environment is accessible at any time; students can use it outside the course hours.

In June 2012 before the summer break (i. e. at the end of the lab session but before the exam preparation), the students were asked about the usefulness of the e-learning environment and rated it positively. 162 stated that the application of the computer-based learning environment was useful. On the given scale from 1 (strongly disagree) to 5 (strongly agree), the arithmetic mean of the results was 3.7 with a standard deviation of 1.3. Since 3 would be neutral, the students evaluate the environment positively without being stunned.

After the course, the environment has been evaluated by the teaching staff. We conducted four interviews. Three of them with student assistants who acted as tutors within the practical exercise and the exam preparation and who were also responsible for adding contents to the knowledge map and solving technical issues. One interview

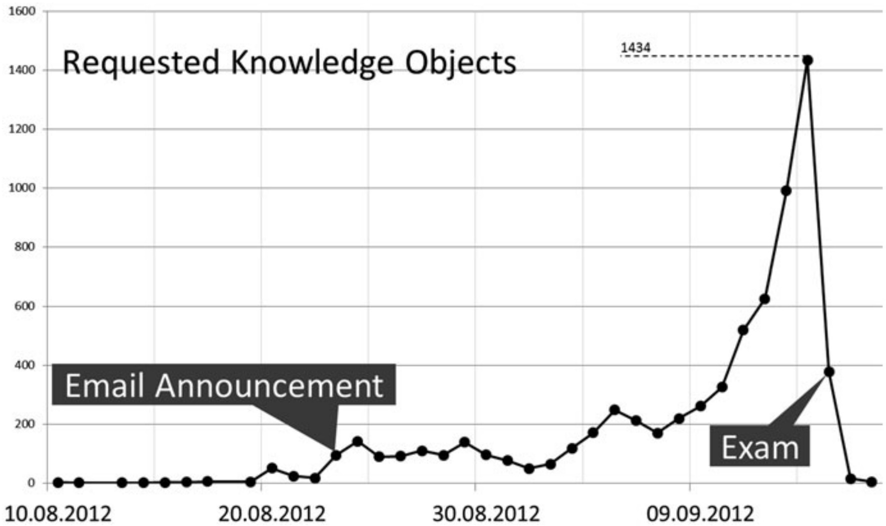


**Fig. 6** Requested knowledge objects by day

was conducted with the lecturer who was responsible for the overall coordination and involved in the planning and conception of the whole course.

In the interviews we asked the participants to rate several statements on a scale from 1 (strongly disagree) to 5 (strongly agree) and explain their ratings. Moreover, we asked them to comment on the strengths and weaknesses of the environment and to suggest improvements. The students' positive judgement of the environment has been corroborated by the teachers. For each statement the arithmetic mean (AM) and the standard deviation is given (SD) (in interpreting these measures one has to keep in mind that only 4 persons rated the statements):

- *The environment was useful for the students.* AM: 4.25, SD: 0.43
- *The environment was useful for me in my role as a lecturer/tutor.* AM: 4.00, SD: 0.71
- *The students reached the learning goals better because of the environment.* AM: 4.00, SD: 0.71
- *I reached my teaching goals better because of the environment.* AM: 3.50, SD: 1.12
- *I would advice the students to use such environments more often if they had access to them.* AM: 4.75, SD: 0.43
- *I would use such environments more often for teaching if I had access to them.* AM: 4.67, SD: 0.47
- *I would use such environments more often for learning if I had access to them.* AM: 3.25, SD: 1.79 (This is an interesting result: Why do the lecturers/tutors rather advice their students to use such an environment than use it themselves? The Interviewees answer that their personal learning style is not optimally supported

by such an environment, because firstly they prefer not to browse through learning contents but to study text books and other material, in particular exercises and exam questions from previous semesters, from beginning to end. Secondly, they prefer using pen and paper over doing all exercises with the computer. Therefore, they request an export to PDF so that they can print selected parts of the material.
- *I consider the environment used within his course as a didactically sound means.* AM: 4.50, SD: 0.50

According to the interviewees, the strengths of the environment were, firstly, that the knowledge map gave a clear overview on the course contents and their interrelationships. The students got a starting point for browsing through the material and exploring the themes independently. Questions could be answered by pointing to specific objects on the knowledge map, and students could (and did) answer their follow-up questions themselves by exploring the surrounding/linked objects. Thereby, the autonomy of the student was effectively supported. Secondly, the chat widget allowed fast feedback from the students. Questions could be immediately answered. Since all students could read the answers, questions did not have to be answered twice. Thereby, the tutors' explanations became more efficient. The tutors saved time for helping with truly individual problems. Thirdly, the environment improved the communication among the students and thereby collaborative learning. After a short time span the students began to answer questions of other students. Fourthly, the environment rendered the students more flexible regarding their time management and learning speed. They were able to repeat lessons and exercises without losing track of the course or thwarting others.

Concerning the weaknesses, the interviewees found technical and usability issues, in particular regarding the administration of the environment and the adding of new contents to the knowledge map. These issues have to be solved but do not affect the concept and general design of the environment. Moreover, the interviewees propose the following extensions of the environment:

- The chat widget should be exchanged or supplemented by a forum for general questions and by a commentary function for the elements of the knowledge map. This would improve the linking of contents with questions and comments.
- They consider a learning planer, consisting of a simple to-do list with links to exam-related material and topics, self-tests and a visualisation of the current level of knowledge/exam preparation progress (related to the self-test results) as extremely useful.
- The interviewees agree that the contents are the most important feature of the environment. These have to be updated regularly.
- So far the contents of the knowledge map are explored by browsing. An additional search engine for the direct search of specific content would be reasonable.
- One interviewee deems a recommender system that recommends related external material useful.

One aim of offering the ROLE environment was to support SRL. Has this goal been reached, that is, did the environment effectively support self-regulation? The interviewees claim that this is in fact the case. While in the beginning a lot of trivial questions were asked, the students were able to find the answers to such simple questions themselves soon. (The question is, however, whether we can attribute this development to an improvement of self-regulation or rather to a learning effect regarding the course contents.)

The interviewees considered it important to support SRL. They estimated that by far most of their students had medium SRL-level. They correlated the SRL-level with the general knowledge level and acknowledged that students with a high SRL-level learned better and faster. However, as tutors and lecturers they generally preferred to teach students with a medium SRL-level over students with a high SRL-level. They justified this preference as follows:

- A tutor was supposed to lead interesting discussions with high SRL-level students. However, they did not need a tutor that much and therefore did not get in close contact to them. Teaching often did not really take place. Moreover, these students tended to be good students that asked difficult questions. A teacher had to be well-prepared and feel certain on the course topic to cope with these questions. This made it sometimes harder to teach students with a higher SRL-level.
- Medium SRL-level students were intelligent but still requested interaction with a teacher. The teacher got in contact with them, observed the learning progress and saw the positive effect of explanations and assistance. The interviewees found this very rewarding.
- The interviewees considered that a low SRL-level is correlated with rather low learning success. Teaching students with a general low level was considered to be cumbersome and not very rewarding.

Feedback given through the environment was recognised by teachers as very important. The interviewees emphasised the role of the chat (or a forum). Feedback was deemed important for estimating the students' progress and thus adjusting interventions. Moreover, it makes teaching more satisfying.

## 6 Conclusion

A course design for information management in mechanical engineering was presented. The course had been re-designed to better support SRL. Therefore, an e-learning environment with several ROLE widgets was provided to the students. The environment aimed to support individual exam preparation. In comparison to the lecture of 2011, the evaluation showed the necessity of intensive promotion for new and additional e-learning tools. Tool objectives and advantages must be clearly communicated (at the right time) to the students. Nevertheless, only a minority of all students had used the test bed for a longer time. Here, guidance with learning questions as in [7] may motivate students and foster communication. Until now, overview and learning guidance is given by the visualisation of topic relations on the start page, the hierarchical and object-oriented organisation of knowledge in the map and the linking of knowledge objects.

To take stock, the evaluation of this test bed has shown that the environment supports SRL and collaborative learning in large classes. The answering of student questions was easier via the chat widget than by email as all students were able to see the answer. Additionally, the chat fostered student-to-student support. Even if the test bed offered support for early learning, the peak of usage was reached just before the exam. It indicates the students' remaining in power learning.

The test bed was implemented as a cloud learning application combining widgets as services in an overall application and using IWC for communication between the widgets. Since different people were responsible for the particular widgets, it was sometimes hard to fix problems e. g. when server were not accessible.

Until now, the test bed was aimed to demonstrate the possibilities of ROLE technology in large classes. The demonstration was successful and further development has to focus more on the learning requirements of students. Therefore, future improvements are seen in better communication and feedback support to strengthen e. g. learning motivation. Suggested improvements are firstly better collaboration support by adding improving topic-related communication (forum, notepad linked to contents of knowledge map) and secondly better SRL-support by adding a learning planer that supports planning (to-do list) and reflection (self-tests, visualisation of progress). The offering of learning strategies such as learning questions [7] within the learning tool may offer new advantages and motivation for the students.

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# Part III
# Cognitive IT-Supported Processes for Heterogeneous and Cooperative Systems

# A Mechanism to Improve Stereo Vision Systems in Automated Heterogeneous Platoons

**Mohammad Alfraheed, Alicia Dröge, Max Klingender, Daniel Schilberg and Sabina Jeschke**

**Abstract** Due to their low price and good quality, Stereo Vision Systems (SVS) are recently considered as a key factor to gather actual information about the object of interest. Today, automated highway systems (AHS) for urban and highway environment were developed without the use of a stereo vision system. In future, the application of AHS should be extended to unstructured environments (e. g. desert) and be adapted to heterogeneous vehicles. In this context, the stereo vision system could enable the platoon to be independent from environmental structure (e. g. lane markings) through its ability to detect, track, locate and recognize heterogeneous vehicles. So far, the need for high accuracy prevents SVS to be applied in automated heterogeneous platoon. In this paper a mechanism towards this is presented, where some behavioral properties have to be satisfied in terms of unstructured environment and heterogeneous platoons. Within a heterogeneous platoon, the back view of a preceding vehicle (BVPV) is considered as a reference point for the lateral and longitudinal control. The key idea of the proposed mechanism is to confirm that the distance of the BVPV can be extracted without depending on the movement of the preceding vehicle. Furthermore, the proposed mechanism has to ensure that features extracted from the back view are suitable to implement successfully the calibration process at around 10 m distance. With the proposed SVS mechanism some of behavioral properties have to be satisfied in terms of unstructured environment and AHS. These properties are reliability, performance and robustness. Compared to other methods which use a SVS, the proposed mechanism distinguishes itself through adapting to dynamic environment and extracting the necessary features for the calibration process.

**Keywords** Stereo Vision System · Automated Highway System · Unstructured Environment · Detection and Tracking · Feature Extraction

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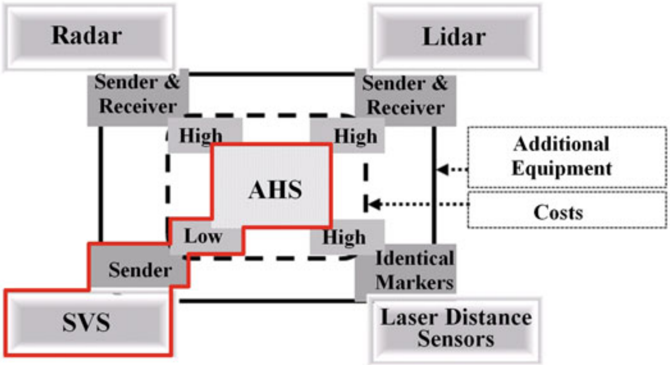


**Fig. 1** Comparison of costs and equipment for advanced measuring sensors

## 1 Introduction

The accurate localization of moving objects plays a crucial role in automated systems. Furthermore, the ability to measure the distance of surrounding objects is a key ingredient of robotic systems. Compared to advanced measuring sensors (i. e. Radar, Lidar), a Stereo Vision System (SVS) performs less well [1], but it comes at a much lower price, see Fig. 1 [2]. Moreover, it can recognize the captured objects without the need to fix any additional equipment e. g. identical markers onto the targeted object.

One application field of autonomous driving is an Automated Highway System (AHS). In AHS only the first vehicle is driven actively and the following vehicles automatically. These vehicles drive closely behind each other with just the necessary safety distance in order to optimize highway capacity [3, 4]. Each vehicle (except the first vehicle) is thus able to drive with a low air resistance, which saves energy and fuel within a distance of about 10 m [5]. A 10 m distance is required to be able to handle safety issues between vehicles [6]. Furthermore since it is successfully tested in the project Konvoi [7], the 10 m distance is here considered as a fundamental aspect of the platoon.

Several AHS projects have been tested [6–10]. The most recent ones are Energy ITS (Intelligent Transport Systems, Japan) [5] and SARTRE (Safe Road Trains for the Environment, Europe) [11]. The project Energy ITS has been developed in Japan since 2008. In ITS a vision camera is pointing onto the highway to calibrate the lateral control based on lane markings. Since the camera is pointing onto the highway, the system cannot locate and recognize surrounding objects (i. e. the preceding vehicle). Further, the camera is set to only recognize lane markings, another tool is needed to recognize the surrounding objects. The vision system used in Energy ITS can be developed further with an SVS pointing along the highway so that it is able to recognize not only the lane markings but also surrounding objects.

The Ricardo UK Ltd company started the project SARTRE in 2009. [11, 12] The project also depends on a vision camera for lateral control but the camera is pointing along the highway. Although the system is able to detect and recognize the preceding vehicle, it would not be able to measure the distance of the preceding vehicle based on only one vision camera. Therefore, additional measuring sensors to localize the vehicle in 3D are needed. Most of the recent researches assign the task of 3D-localization to advanced measuring sensors due to their high performance. So far no AHS has been equipped with an SVS to take over the 3D localization task.

In future, the application of AHS should be extended to unstructured environments (e. g. desert) and be adapted for heterogeneous vehicles (e. g. passenger cars and trucks). This would be especially beneficial for an application in third world countries who do not have well-developed infrastructures but suffer from traffic jams and congestions. Several challenges prevent the developed systems to be applied in unstructured environments. Some of these challenges relate to unpaved environment where there are 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. To solve these challenges the SVS is installed on the front of the vehicles. Further, the SVS enables the platoon to be independent from environmental structure through its ability to detect, track, locate and recognize the preceding vehicle and uses it as a reference. The 3D motion vector can be measured for the Back View of the Preceding Vehicle (BVPV). The need for high accuracy prevented SVS so far to be applied in automated heterogeneous platoon. In this paper, a solution is proposed to figure out to which extent one can rely on a SVS in an automated heterogeneous platoon.

Within a heterogeneous platoon, the BVPV is considered as a reference point for the lateral and longitudinal control. This would be especially beneficial since a joint region is provided between the left and right image of the SVS. That region enables the mechanism to restrict its function to a particular part of the frame instead of processing the whole frame. As a result, the running time of the calibration process is reduced since pixels, which are outside of the BVPV, are ignored and thus do not have to be processed.

Subsequently, the detection and tracking process is needed to have the BVPV available whenever the calibration process is repeated. Therefore, the key idea of the proposed mechanism is that the distance of the BVPV can be extracted and confirmed without depending on the movement of the preceding vehicle. Further, the proposed mechanism has to confirm that features extracted from the reference object are accurate enough to successfully implement the calibration process at around 10 m distance (i. e. the number of control points has to be higher than 64 [13]). Moreover, the BVPV is able to enable a joint region between left and right image in order to restrict the correct values among results extracted from the calibration process.

Since the proposed mechanism is applied in unstructured environment, several challenges have to be overcome first. Some relate to a clear visibility of the BVPV (i. e. the sunshine reflection), others arise due to the real time constraints associated with AHS and the modern version of the SVS (e. g. Bumblebee2).

This paper is organized as follows: Sect. 2 discusses the recent research on SVS. The proposed mechanism of the SVS is described in Sect. 3 and the results of the proposed mechanism in Sect. 4. A conclusion is given in Sect. 5.

## 2 State of the Art

Recently, Paul et al. [14] developed and demonstrated a method to fuse measurements from a stereo vision system, six-axis force-torque sensor and other sensors. Their main goal was to detect, track and localize a grasped object based on model-based estimation methods. However, the mandatory use of these sensors (e. g. six-axis force-torque sensor) is incompatible with proposed work here which aims to use SVS only.

A different approach was presented in [15] based on 3D system architecture consisting of a SVS and Time-Of-Flight (TOF) cameras. Although the approach depends only on visions cameras, the distance between the grasped object and the system was not measured by SVS but by TOF. Furthermore, the object of interest was identified and located using a database of a priori acquired object models. Since the AHS is intended to be applied in dynamic environments, the database of the captured objects is requested to update itself whenever any captured object is detected.

Based on the equipment (SVS + TOF) another approach was implemented for object localization and integrated on the DESIRE (Deutsche Servicerobotik Initiative) experimental platform [16]. Within the project DESIRE, the operation distance is 1.5 m. In AHS, the distance between vehicles is about 10 m due to the necessary safety distances between platoon vehicles [6, 7]. Therefore, the operation distance of 1.5 cannot be satisfied in AHS.

As mentioned above, most of the real time applications (i. e. intelligent robotics) combine the SVS with advanced distance sensors (e. g. TOF) due to the limitation of the real time constraints. Jin et al. [2] presented a hardware architecture for real-time stereo vision. The architecture was integrated within a single chip in order to overcome real time constraints. Despite of the successful results achieved within the indoor environment, they did not consider a dynamic environment where both SVS and the object of interest are moving. Since AHS move in a dynamic environment this method cannot be used for SVS purposes.

In order to improve the real time performance of a SVS, Pinhas and Xin Xu [17] have proposed an embedded stereo vision system in autonomous mobile robots. Many commercial stereo vision system are recently available on the market and they have the ability to be applied under real time constraints (i. e. Bumblebee2, nDepth, Videre, etc.) [17]. These commercial systems [2] implement the calibration process at the starting point. Since the calibration process can be implemented under real time constraints, the SVS is able to repeat the calibration process whenever there is a need to generate the depth map again. In AHS, the appearance of the BVPV is often changed by environmental effects (i. e. sunshine reflection). In addition, the preceding vehicle is often moving away from the SVS. Therefore, the 3D-position of the BVPV becomes faulty sometimes be faulty and the calibration process will not be able to recognize features of the back view at a 10 m distance. The features enable the SVS to generate the depth map of the BVPV. So, the calibration is not accurate enough to measure the distance between the preceding and following vehicle. To solve this problem the calibration process has to be adapted for those environmental effects. Furthermore, the location of the BVPV has to be detected and tracked while the SVS is moving.

Based on the object detection and tracking developed by Kim et al. [18] a SVS was enabled to track an object and to measure its distance in real time. Within their works, they used a ball grasped by a hand as an object to calibrate the SVS. Although the error was very small, it is not practical to position a particular object in front of the SVS whenever the calibration parameters are reconfigured. In addition, the ball location has to be clearly visible for detection and tracking. However, within a dynamic environment, this is not always the case.

The limitation of the distance is extended to about 250 cm by Li-wei Zheng [19]. They developed a system that can automatically detect and localize 3D features in motion. The drawback here is that a manual selection for marking a feature point of interest was used. To avoid the manual selection Lee Chonge Wan et al. [20] developed a stereo vision tracking system based on a tracking algorithm and a depth estimation method. They used human skin as a reference object for SVS. However, the possibility to use a physical material (i. e. human skin, chessboard) in AHS is impossible.

Petric et al. [21] used the standard game console joystick merging with infrared camera for an active real-time 3D marker tracking. The working distance of the infrared lights limits the distance between preceding and following vehicle to about 3 m. In AHS however, the distance should be around 10 m or more [7, 8].

Stephan et al. [22] developed a dynamic stereo vision system which is capable of detecting and tracking a person within 4 m. Since they assume that the background is constant and the system reacts only to changes, their system cannot be applied in a dynamic environment. The same goes for the work of Litzenbeger et al. [23] which used this method to track pedestrians and vehicles.

In contrast, the dynamic environment was considered by Wook Bahn et al. [24]. The SVS was installed on the top of a mobile robot platform which was moving in a closed room. Furthermore, the authors proposed a control system to maintain the line of sight of the stereo camera towards a stationary target by using the robot motion data. However, the test environment offered not enough changes to simulate the dynamic environment in AHS.

Measuring the position of the moving object under dynamic circumstances (i. e. irregular object motion) is a key task in automotive driver assistance system. Recently, the 6D vision project [25, 26] has successfully measured the position of the moving objects (three dimensions). The 6D Vision project used a SVS and a new algorithm called Dense6D [27] in order to estimate the motion field of the moving object. Despite of the robust and accurate results generated by the estimation process, it requires that the object is always moving to generate the optical flow vectors. Within AHS, the coupling between the preceding and following vehicle is sometimes generated at the start without moving. Further, both preceding and following vehicles are moving with the same velocity and in the same direction so it looks like as if the preceding vehicle does not move. Since the optical flow of surrounding object is generated based on the movement of the object, the optical flow vectors of the BVPV are not generated well.

## 3 The Proposed Mechanism for Improving Stereo Vision System

Estimating the three-dimensional motion vector field using the (SVS) is an important task for autonomous vehicles. Although using a SVS is a traditional way for measuring a distance of a target object it still has advantages in terms of safety, undetectable characteristics and reliability [28].

In this paper a mechanism for an SVS is presented to enable heterogeneous platoons in outdoor environment. A method to calibrate a SVS outdoors has already been published elsewhere by Dennis Mitzel et al. [29]. Therefore, this work proposes a mechanism to run a SVS based on the detection and tracking of an object. Hereby, the SVS has to extract the necessary features of the target object in order to reduce errors associated with the calibration process. Here, the mechanism to provide the necessary requirements to adapt a SVS to the unstructured environment and heterogeneous platoon is presented and discussed. Thus, the calibration process is faster, more accurate and robust against calibration errors. Further, the mechanism can be used with automated heterogeneous platoons.

With the proposed SVS mechanism, some behavioral properties have to be satisfied in terms of unstructured environment and AHS. These properties are as follows:

- Reliability: For SVS the running time of the calibration process has to be reduced to fulfill the real time constraints.
- Performance: It has to satisfy that the calculation error associated with the matching process is almost eliminated at a 10 m distance.
- Robustness: Regarding failure handling the mechanism has to be able to handle the failure generated by the localization process of a dynamic object.

Figure 2 shows the flowchart of the proposed mechanism, where five components communicate with each other. The first, the "object detection" determines the target object. A supplement process is needed to follow the target object, which here is called "object tracking" – the second component. Merging the 2D-Coordinates of the back view generated by the detection and tracking process is presented in the third component "merging process". In the fourth "feature extraction" the necessary target object features are extracted. Finally, a "calibration process" is required to measure the main parameters of the SVS (i. e. internal parameters of the SVS), which is presented in the fifth component.

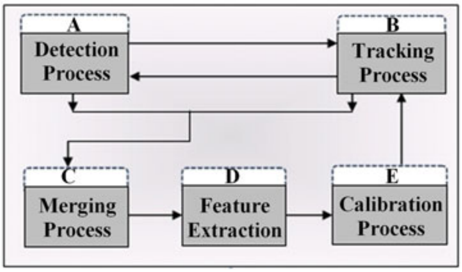


**Fig. 2** The proposed mechanism for SVS

### *3.1 Detection Process*

Within the detection process, the target object is located in 2D coordinates using an intelligent agent. Concerning the solution proposed for the next generation of AHS in unstructured environment [1], the BVPV is chosen as a reference point (target object for the SVS) in unstructured environment. Results associated with the detection process have been already published [30]. In context of reliability, the running time of the back view detection is 12–30 frames/second. Moreover, since the detection process is able to extract various features of the BVPV whenever it is affected by environmental effects (i. e. sunshine reflections, darkness) the detection process is robust against dynamic environment.

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 to detect the BVPV. The single agent in turn detects features, which distinguish the BVPV from the environment as well as from different shapes of vehicles.

As an output, the 2D-coordinates of the back view are transformed to the next process; either the tracking process or the feature extraction. If the tracking process fails to follow the back view the last position of the back view (as input) is received to detect again the back view. Based on this input, the detection process will be able to predict the next location of the back view in the next video frame.

### *3.2 Tracking Process*

The agent of tracking process is a supplement to the detection process. The latter's main goal is to determine the initial location of the back view. The tracking process follows the back view based on the estimation of its location in the next frame. Meaning that, the tracking process checks only the predicted region of the back view instead of checking the whole frame again in order to save the running time of the tracking process. The coupling between both processes enables the proposed mechanism to follow the BVPV whenever the tracking process fails to determine the next position.

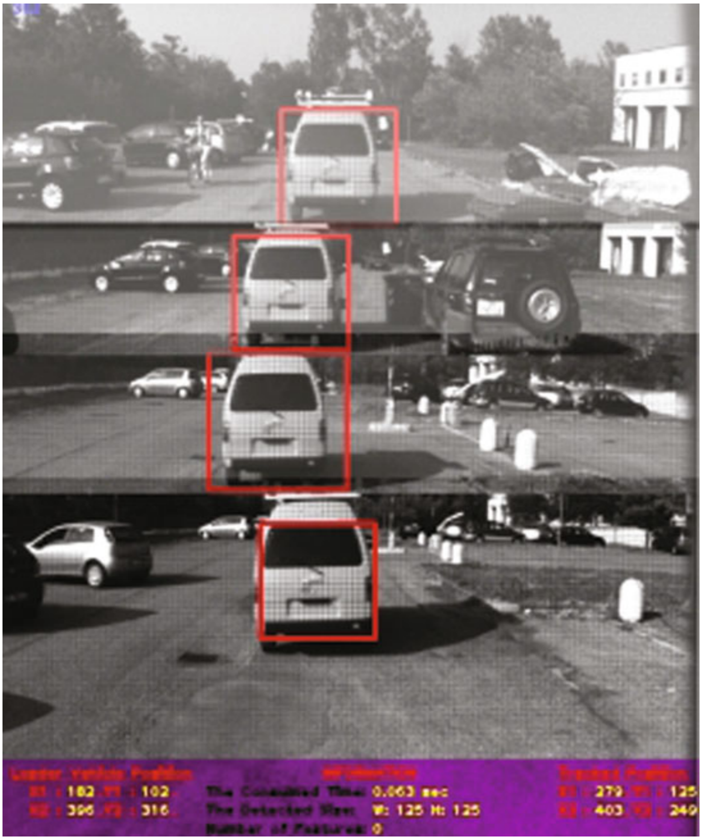

**Fig. 3** BVPV tracking results after 69, 120, 280 and 312 s from the starting point

The criterion used to estimate the next location of the BVPV is to extract the largest possible area, where its upper edge is the level of the vanishing point and the center point of the new area is the same center point as of the previous detection. In addition, the size of the search area should be close to the size of the previous detection. Thus the tracking method automatically cuts out the region in which the BVPV is located instead of checking the whole frame.

Regarding reliability, the tracking process follows the BVPV under real time constraints with a running time of 16–66 frames/s. Figure 3 shows the traced BVPV after 69, 120, 280 and 312 s from the moment the platoon was formed. Furthermore, the tracking process is able to follow the BVPV when it is affected by environmental effects.

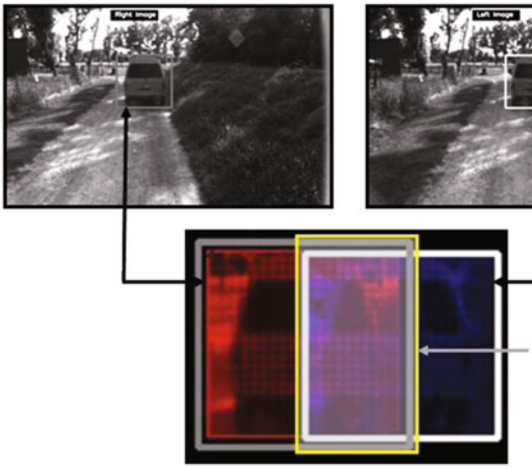


**Fig. 4** The merged image of the SVS based on an overlap of the left and right deteected back view

### *3.3 Merging Process*

After having the 2D coordinates of the back view from left and right image, the merging process (shown in Fig. 4) is responsible to merge both coordinates in one image. As a result, the object's coordinates (e. g. in left image) are determined in the corresponding image (e. g. right image) without the external parameters of the SVS (i. e. the distance between right and left camera). The reasons behind this merging are as follows:

The first reason is that the suitable size of the disparity image needs to be measured, meaning that the calibration process has to generate a disparity image for the depth map. The disparity image [31] obtained from stereo matching, in turn, must have a particular width and height in order to estimate the 3D vector. In case the size of the disparity image is larger than or equal to the size of the original image (e. g. left or right image) some of the neglected pixels (pixels located outside the white or gray rectangle, Fig. 4) are considered in the calibration process. A smaller disparity image size eliminates pixels associated with the back view so that the merging process determines automatically a suitable size which covers only the back view.

The second reason is to reduce the running time assigned with the calibration process. The normal procedure of the calibration process is to transform each pixel in the merged image of SVS into 3D motion vectors. In case the suitable size of disparity image is defined, the transformation step is only applied over those pixels associated with the back view. As a consequence, the running time assigned to the calibration process is logically reduced.

The third reason is to measure the joint region between the left and right image of the SVS. The joint region is extracted through subtracting the 2D coordinates of the left upper corner of the gray rectangle (right image) from the 2D coordinates of the white rectangle (left image, Fig. 4). The joint region plays an important role to increase the performance of the detection and tracking process. For instance, the detected and tracked coordinates of the back view support each other whenever the back view cannot be detected or tracked in the left or right image. Furthermore, the existing coordinates of the previous extracted regions are recorded to predict the next position of the back view in case it cannot be detected.

### *3.4 Feature Extraction*

The correspondence for both right and left image of SVS is considered as a significant step in the calibration process. This is because both images need to be matched to generate the disparity image. The matching uses the same objects features in both images in order to find the corresponding points. One of the classical methods is the Chessboard method [13]. The chessboard represents the target object of the calibration process and it has to be positioned in front of SVS. The method, in turn, detects the corners of the white and black square and uses them as corresponding features for the matching process. Due to the need to calibrate the SVS while the platoon of AHS is moving the Chessboard method cannot be applied in AHS.

The SURF method [32] (Speeded-Up Robust features) extracts the corresponding points for both the right and left image without the need to position any target object. The idea behind SURF is to extract features associated with the captured scene (e. g. trees, street, etc.). The SURF method was able to find the corresponding points [32]. In AHS, the dynamic environment represents a challenge for the SURF method. The corresponding points are sometimes not clearly visible due to environmental effects (i. e. sunshine reflection) and the long distance of the BVPV. The proposed mechanism aims to define the BVPV to be a reliable reference of the automated heterogeneous platoon for the calibration process. Therefore, the SURF method is used as a tool to prove that the mechanism is able to extract enough features for the calibration process.

The feature extraction aims to extract many features of the back view (i. e. ca. 64 features points [13]). The extracted features, in turn, enable the mechanism to detect the control points needed to match the left and right images of the SVS. [13] Fig. 5a shows features extracted from the back view while the preceding vehicle is moving in unstructured environment. These features are extracted from the SVS (e. g. from left image) at about 8 m distance. To show features more clearly a zoom-in view is shown in Fig. 5b for a sample of these features. Based on the coordinates of the correspondence generated as a result of the previous step, the corresponding features in the other image of the SVS (e. g. right image) are extracted. As a consequence, the control points required to match both left and right image are efficiently extracted. Meaning that, the correspondence between each pair of those points has a high accuracy due to similarity between extracted features. Furthermore since not the whole image has to be checked, the running time consumed to extract those control

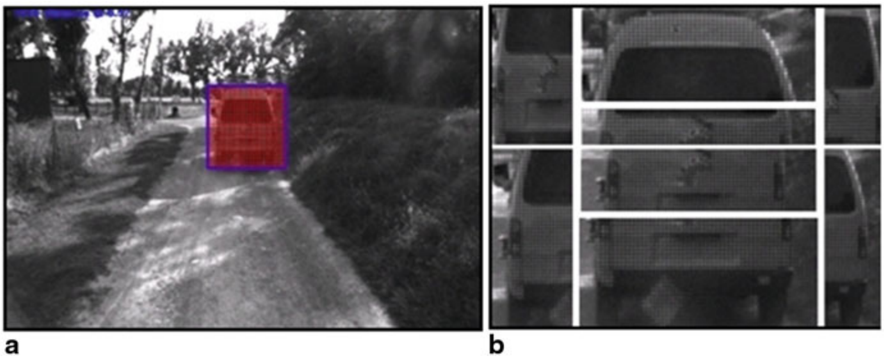


**Fig. 5** The extracted features of the back view. **a** All of the extracted features. **b** Samples of features based on zoom-in-view

points from the corresponding features is shorter than the running time consumed to extract points from the whole image [33].

### *3.5 Calibration Process*

Within this process, the mechanism extracts the internal and external parameters of the SVS. The latter represent the relative position of the SVS, the former the position of the principal points, focal lengths and aspect ratios [34]. The calibration was already done by the Artificial Vision and Intelligent Systems Laboratory (VisLab) of Parma University in Italy [35]. Therefore, this work aims to introduce a mechanism to run the SVS robustly in dynamic environments. However, this work depends on the SVS used by VisLab. The necessary parameters are as shown in Table 1.

## 4 Results and Discussion

To check the results of the proposed mechanism, the merging process and feature extraction are run on experimental data. Regarding the results of the detection process have been published in [30]. As for the tracking result is going to be published elsewhere. Since the calibration process is already implemented by the Artificial Vision and Intelligent Systems Laboratory (VisLab) of Parma University in Italy [35], the discussion does not include results of the calibration process.

The SURF method has been applied on the experimental data as shown in Fig. 6 in order to figure out how many corresponding points can be extracted using the whole image. The extracted points which are outside the BVPV in both right and left image are highlighted in white and points inside are gray. The corresponding points

**Table 1** The internal and external param of the SVS

| Parameter Name | Values | | Description [unit] |
|---|---|---|---|
| | *Left camera* | *Right camera* | |
| | | *Internal param* | |
| Angular FOV | 0.505745 & 0.364893 | 0.493941 & 0.36745 | Angular field of view (FOV, aparture) of the installed optic. Measured in two directions: horizontal and vertical. [rad] |
| Optical Center | 350.058 & 258.099 | 348.077 & 263.327 | Includes the coordinates of the optical center. [number or pixels] |
| Pixel Aspect Ratio | 1.0 | 1.0 | Specifies the ratio between the height and width of the pixel. |
| | | *External param* | |
| Position | – 0.54 & 0.39 & 1.675 | – 0.54 & – 0.41 & 1.675 | A sensor position vector, with 3 coordinates (X, Y, Z), where X is positive in venicle motion direction, Y is negative towards the right camera, Z is positive pointing upwards. [m] |
| Orientation | 0.0309407 & 0.185446 & – 0.0122179 | 0.028695 & 0.192886 & – 0.0152795 | Orientation vector including three values: YAW, PITCH and ROLL. [rad] |

generated by matching process of the SURF method are linked together by a white line.

The disparity image assigned to the back view has to be accurate enough to generate the depth map associated with it. In case the preceding vehicle is moving away from the SVS, the number of the corresponding points of the back view is not high enough to generate an accurate depth map. Based on the calibration method presented in [13] the number of the corresponding points should be around 64 (the same number of the chessboard corner). As shown in Fig. 6, the number of the corresponding points of the BVPV is 4 at about 8 m distance to the preceding vehicle.

Although there are many extracted points of the BVPV, the number of the corresponding points is 4. In case the whole image is used as a target object, the number is still less than 64. Starting from this challenge, the extracted features are used to increase the number of corresponding points by using them to match left and right image. Thus the corresponding points generated by SURF are increased to more than 64. As shown in Fig. 7, samples of the corresponding points of features are generated and the actual number is about 101 points.

In order to satisfy the non-functional requirements of the proposed mechanism, it has to infer three behavioral properties:

The first property (**reliability**) represents the mechanism's ability to reduce the running time associated with the transformation process of disparity values. The normal procedure of SVS applications is to transform the whole disparity image into

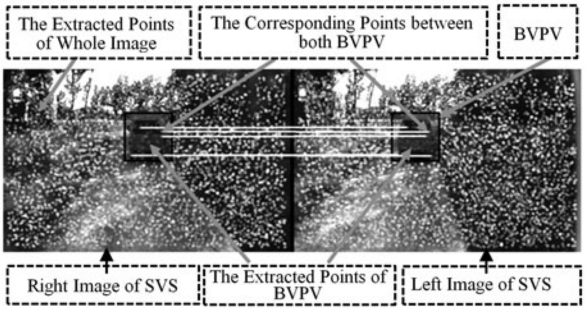


**Fig. 6** Results achieved by SURF method using the whole right and left image

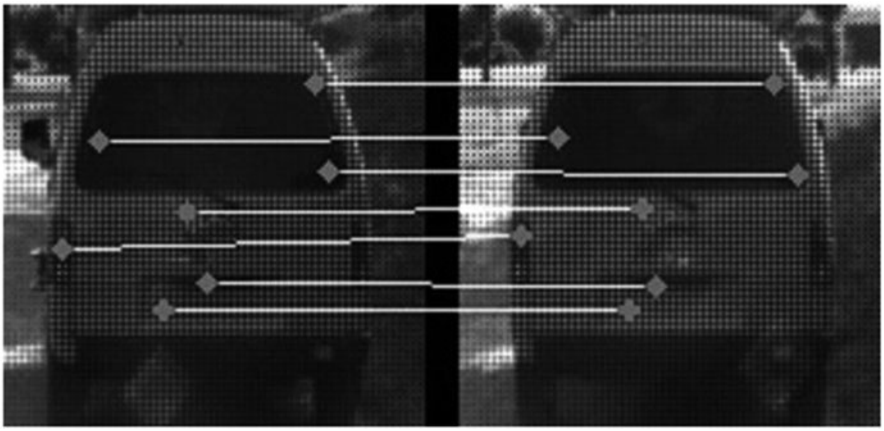

**Fig. 7** Sample of the corresponding points of the extracted features

depth map despite of the need to monitor a particular object [17]. The idea behind the proposed solution is to just transform the disparity values associated with the back view instead of using all of disparity values. Since the mechanism determines the expected size of the BVPV (as shown in Fig. 8) at different distances of the preceding vehicle, the SVS is then able to transform only pixels assigned to the BVPV. Subsequently, the SVS can only generate disparity values which it needs. Therefore, the running time assigned to the calibration process is reduced.

The second property is the **performance**. Here, the calibration process has to reduce the calculation error as much as possible. The first step to reduce it is to increase the number of matching points (as discussed with Fig. 7). If these points are increased, the error is reduced [13]. Measuring the suitable size of the disparity image is the second step (as discussed in the merging process of Sect. 3). The suitable size should cover the back view. In case the size of the disparity image is less than the size of the back view, all 3D-vector values associated with the back view are not considered in the distance calculation of the preceding vehicle. In contrast, the large

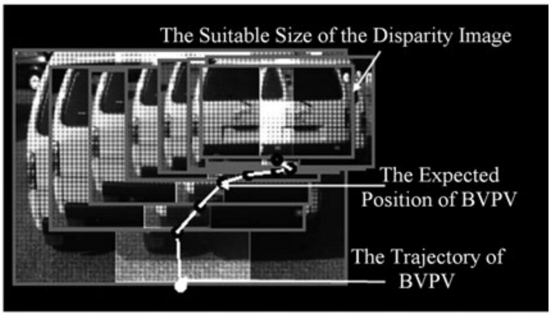


**Fig. 8** The trajectory of the BVPV and the expected size based on different distance of the preceding vehicle

**Table 2** A comparison with other methods

| Parameter→ ↓Method | Using a corresponding method | Number of frames | Saving a trajectory |
|---|---|---|---|
| ME | No | 1 | Yes {dynamic environment} |
| Dense6D | Yes {optical flow} | 2 | No |
| Embedded features-based | Yes {canny detector} | 1 | No |
| information-based motion | No | 1 | Yes {static environment} |

size includes the values of the surrounding object (i. e. street) and then the dispersion between the gathered values is increased. Based on the proposed mechanism, the suitable size can be determined (see Fig. 8) at different distances where the size is marked as a gray rectangle. Since the mechanism is able to carry out both steps, it property "performance" is ensured.

Regarding the last property (**robustness**), the mechanism has to be robust enough against the detection and tracking failure. As shown in Fig. 8, a joint region is defined to generate the trajectory of the preceding vehicle. The path is generated by using the middle point of the bottom edge of the joint region. The existing data of the joint region (i. e. the position of the middle point and the suitable size of the disparity image) enable the SVS to predict the next position of the BVPV. Consequently, the next position of the BVPV is determined in 2D-coordinates. Moreover, the joint region is useful to predict the next size of the back view. Therefore, in case of failure (detection, tracking or both), the mechanism is able to handle the failure and to predict the next position and size of the back view.

Compared to other methods the proposed mechanism distinguishes itself through adapting to dynamic environment and extracting the necessary features for the matching process. Table 2 shows a comparison between the proposed mechanism (ME), dense6D [27], embedded features-based [17] and a motion information-based [24].

Three parameters are used for the comparison. The first “Using a Corresponding Method” shows whether the method uses a corresponding method to extract the similar features of both right and left image. The second parameter “Number of Used Frame” represents how many frames are used to find the correspondence between both left and right images. Finally, “Saving a trajectory” represents the method’s ability to record the trajectory path of the captured object over several frames.

Starting from the first parameter, the proposed method and the motion information-based do not use the corresponding method. But the motion information-based method depends on the gyroscope and encoders to perform the matching between left and right image. In contrast, the other two methods (dense6D and embedded features-based) use an optical flow method and canny detector to determine the matching between the left and right image. Therefore, the proposed mechanism is able to save the time consumed in the matching process.

Regarding the second parameter, the proposed mechanism uses one frame to find the match between left and right image like the other methods (embedded features- and motion information-based). Considering the first parameter, the mechanism is able to determine the match using one frame without corresponding methods or control points. Thus, the run time of the calibration process is reduced.

Finally, the last parameter shows that the mechanism is able to record the trajectory of the preceding vehicle in a dynamic environment using the joint region. This feature is also implemented in the information-based motion, which however has only been tested in indoor environment and thus might not function outdoors.

In summary, the running time of the proposed mechanism is faster than other methods. The reason behind this fact is that the proposed mechanism is able to match the left and right images of the SVS using its detection and tracking components, and further the mechanism does not use other tools (i. e. canny detector, optical flow) to find control points. Since the mechanism is developed to generate a trajectory of the BVPV, the latter enables the mechanism to be adapted to unstructured environment which represents a challenge for the future developments of the AHS. In other words, the proposed adaptation delivers the existing data (i. e. the current position of the BVPV, the current size of the disparity image) which enables the heterogeneous platoon to be electronically coupled in sharp turns and winding roads.

## 5 Conclusion

The SVS distinguishes itself from other vision sensors in terms of safety and low cost. Within this work a mechanism to use the SVS for automated heterogeneous platoons and in unstructured environment is presented. This mechanism has to function under real time constraints and overcome the challenges (dissolving problem in sharp turns and with unclear visibility) associated with AHS. The SVS requires the matching points between the left and right SVS images, which are showing the BVPV, to successfully calibrate itself and to measure the distance of the preceding vehicle. The proposed mechanism is able to perform the extraction process to generate the necessary number of matching points to enable the SVS to function in an unstructured environment. Based on the detection and tracking agents, the extraction process of these points has been realized using various features of the BVPV located at a 10 m distance. The detection and tracking process also has been run successfully in unclear visibility conditions. Thus the extraction process functions robustly with reduced visibility. Furthermore, the mechanism overlaps the BVPVs located in the left and the right image and thus estimates the suitable size of the depth map. Since the 3D motion vector is only generated for the pixels in the overlap region, the running time of the calibration process is reduced so that, the mechanism runs reliable under real time constrains. It has been shown that the three behavioral properties (reliability, performance and robustness) are satisfied for the mechanism. Further, the current position and the estimated size of the BVPV are saved to generate the trajectory of the preceding vehicle. This is used to follow the preceding vehicle when it disappears and the dissolution problem in sharp turns is solved. Using the BVPV as a reference enables the mechanism to be independent from surrounding objects and allows the detection and tracking of any type of vehicle thus enabling heterogeneous platoons. Next, a function will be implemented to enable the SVS to be calibrated based on the mechanism.

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# Kennzahlen zur Validierung der Reduzierung des Polylemmas der Produktionstechnik durch kognitive Montageplanung

**Christian Büscher, Eckart Hauck, Daniel Schilberg und Sabina Jeschke**

**Zusammenfassung** Im Bereich von Produktionstechnologien haben Hochlohnländer wie Deutschland aufgrund ihrer intensiven Forschungs- und Entwicklungsarbeit häufig einen technologischen Vorteil im Vergleich zu Niedriglohnländern. Diesen können sie jedoch in Bezug auf einen wirtschaftlichen Erfolg nicht immer ausnutzen, da der Einfluss der geringen Produktionsfaktorkosten in Niedriglohnländern zumeist überwiegt. Der Exzellenzcluster „Integrative Produktionstechnik für Hochlohnländer" an der RWTH Aachen University stellt sich dieser Herausforderung und erforscht nachhaltige Technologien zur Sicherstellung der zukünftigen Produktion in Hochlohnländern auf der Basis des sogenannten Polylemma der Produktionstechnik. Es wurde ein kognitives System im Bereich von Montageplanungssystemen entwickelt, das die Vorteile der Automatisierung mit der Flexibilität des Menschen verbindet. Um den Einfluss von kognitiven Systemen auf das Polylemma der Produktionstechnik zu messen, werden in diesem Beitrag vier Kennzahlen, die deren Dominanz innerhalb des magischen Dreiecks (Kosten, Zeit und Qualität) aufzeigen, präsentiert und diskutiert.

**Schlüsselwörter** Polylemma der Produktionstechnik · Kognitives Montageplanungssystem · Kennzahlen · Ramp-up Phase

## 1 Einführung

Im Bereich von Produktionstechnologien haben Hochlohnländer wie Deutschland aufgrund ihrer intensiven Forschungs- und Entwicklungsarbeit häufig einen technologischen Vorteil im Vergleich zu Niedriglohnländern. Diesen können sie jedoch in Bezug auf einen wirtschaftlichen Erfolg nicht immer ausnutzen, da der Einfluss der geringen Produktionsfaktorkosten in Niedriglohnländern zumeist überwiegt. Der Exzellenzcluster „Integrative Produktionstechnik für Hochlohnländer" an der RWTH

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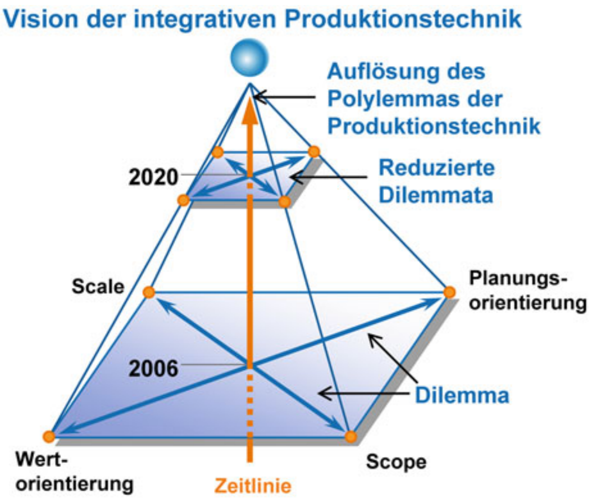


**Abb. 1** Das Polylemma der Produktionstechnik [1]

Aachen University stellt sich dieser Herausforderung und erforscht nachhaltige Technologien zur Sicherstellung der zukünftigen Produktion in Hochlohnländern auf der Basis des sogenannten *Polylemma der Produktionstechnik* (Abb. 1).

Innerhalb des Polylemmas werden zwei Dimensionen unterschieden: die produktionsorientierte und die planungsorientierte Wirtschaft [1]. In diesem Spannungsfeld müssen sich Unternehmen zwischen Scale und Scope bzw. Wert- und Planorientierung positionieren. Die Anforderungen an die Produktentwicklung und Fertigung sind in Bezug auf moderne Produktionstechnologien jedoch nicht mehr ausreichend berücksichtigt. Daher müssen grundlegend neue Methoden und Technologien entwickelt werden, um dieses Polylemma aufzulösen. Ein Aspekt des Exzellenzclusters sind dabei selbstoptimierende Produktionssysteme, die auf kognitiven Fähigkeiten basieren, um sich schließlich selbst in Bezug auf ein gegebenes Zielsystem zu optimieren [2].

Eine der Herausforderungen des Polylemmas der Produktionstechnik besteht darin, den Wertstromansatz zu verfolgen und gleichzeitig eine Effizienzsteigerung der Montageplanung zu erreichen. Dafür wurde ein System mit einer Kognitiven Kontrolleinheit (CCU für cognitive control unit) als Kernkomponente mit dem Ziel der Automatisierung des Montageplanungsprozesses entwickelt [3]. Durch eine eigenständige Planung und Steuerung der Montage eines Produktes, das lediglich durch seine CAD-Daten beschrieben ist, erreicht die CCU unter Berücksichtigung einer *zufälligen* Bauteilzuführung eine Flexibilitätssteigerung während des eigentlichen Montageprozesses bei gleichzeitiger Minimierung des Planungsaufwands im Vorfeld [4].

Um den Einfluss der CCU und kognitiven Systemen im Allgemeinen auf das Polylemma der Produktionstechnik zu messen, werden vier Kennzahlen, die deren Dominanz innerhalb des magischen Dreiecks (Kosten, Zeit und Qualität) aufzeigen, präsentiert und diskutiert:

1. Planungsaufwand
2. Beschleunigung der Produktionsvolumenzunahme
3. Steigerung des Gesamtproduktionsvolumens
4. Planqualität

## 2 Kennzahlen

Die Einführung eines kognitiven Systems wie die CCU beeinflusst vor allem die Ramp-up Phase innerhalb der Produktentstehung, da diese im Bereich automatisierter Montagesysteme eine planungsintensive Phase ist [5]. Die neuen Kennzahlen konzentrieren sich auf den Vergleich von kognitiven und klassischen Systemen zur Montageplanung und -steuerung [6], während allgemeine Leistungskennzahlen zum Ramp-up-Prozess selbst bereits existieren [7–9].

Zu Beginn der Ramp-up Phase ist der Aufwand der Montageplanung in beiden Systemen identisch. Die Programmierung eines kognitiven Systems ist jedoch aufwendiger (z. B. durch Teaching der Bewegungsabläufe) als die klassische Montageprogrammierung. Bedingt durch die höhere Flexibilität von kognitiven Systemen kann die Optimierung im späteren Serienbetrieb schneller erreicht werden. Dieser Vorteil übersteigt nur dann den erhöhten Aufwand in der Pilotserie, wenn auf demselben Produktionssystem mehrere Produkte hergestellt werden. Dies wird dadurch erreicht, dass ein kognitives System in der Lage ist, durch Reaktion auf veränderte Umweltzustände mittels Selbstoptimierung seine Montagereihenfolge zu variieren. Demgegenüber müssen klassisch programmierte Systeme für jede Produkt- und Montagevariante neu angepasst werden. Abbildung 2 zeigt den Verlauf zweier Ramp-up-Prozesse mit Einsatz eines kognitiven und eines klassischen Montagesystems. Die Ramp-up Phase einer Produktion bis zum Erreichen der Kapazitätsgrenze kann durch eine S-Kurve approximiert werden. Die Zeitpunkte $t_{S_i}$ bezeichnen die Erreichung der maximalen Serienproduktionskapazität der einzelnen Produktionssysteme.

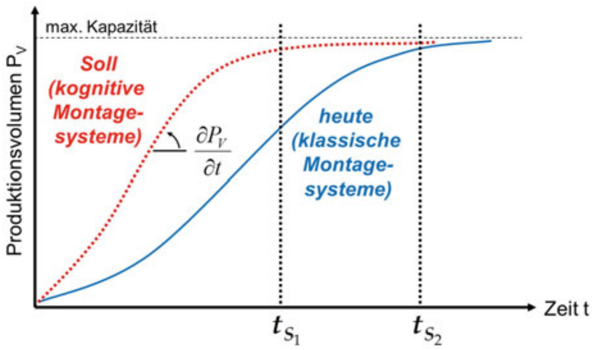


**Abb. 2** Verlauf der Ramp-up Phase mit und ohne Einsatz von kognitiven Systemen innerhalb eines Montagesystems

Die S-Kurve berechnet sich allgemein nach der Gleichung [6]:

$$f(t) = K * \frac{1}{1 + e^{c*(t_w - t)}} \tag{1}$$

Mit

| | |
|---|---|
| $f(t)$ | Anlauffunktion |
| $K$ | maximale Kapazität |
| $t$ | Zeit |
| $t_w$ | Zeitpunkt des Wendepunktes in der Anlauffunktion |
| $c$ | Konstante. |

Diese Gleichung besitzt einen Wendepunkt an der Stelle $t_w$, an der der größte Zugewinn an Produktionsvolumen pro Zeiteinheit erfolgt. In einem klassischen Anlaufprozess entspricht diese Steigung der Lernkurve der am Montageprozess beteiligten Personen. In einem kognitiven System wird dieser Lerneffekt zusätzlich durch die Optimierung des Montageablaufs durch das System selbst verstärkt. D. h., dass ein Produktionssystem mit kognitiven Fähigkeiten schneller sein Kapazitätsmaximum erreichen kann.

## 2.1 $K_{PA}$ – Planungsaufwand

Die erste Kennzahl *Planungsaufwand* bezieht sich auf die Phase der Einrichtung und Programmierung des kognitiven Montagesystems. Die Initialbefüllung der Wissensbasis des Systems stellt dabei einen erheblichen Mehraufwand gegenüber der Programmierung eines klassischen Montagesystems dar. Dieser Aufwand ist für ein Produktionssystem, das nur ein Produkt fertigt, zu hoch, da ein klassisches Montagesystem schnell für einen festgelegten Fertigungsschritt programmiert werden kann. Soll das Montagesystem aber in der Lage sein, ein breites Produktspektrum zu montieren, muss ein klassisches System ständig neu programmiert werden. Demgegenüber kann ein kognitives System mit geringem Aufwand an neue Produkte angepasst werden. Die Kennzahl berechnet sich aus den Aufwendungen der zu montierende Produkte von der Programmierung des Systems bis zur Erstellung der Wissensbasis und der Optimierung.

$$K_{PA} = 1 - \left( \frac{\sum_{i=1}^{n} PA_{i_{kognitiv}}}{\sum_{i=1}^{n} PA_{i_{klassisch}}} \right) \tag{2}$$

Mit

| | |
|---|---|
| $K_{PA}$ | Kennzahl des Planungsaufwands |
| $PA_{i_{kognitiv}}$ | Planungsaufwand eines kognitiven Montagesystems |
| $PA_{i_{klassisch}}$ | Planungsaufwand eines klassischen Montagesystems [6]. |

Durch die automatisierte Montageplanung innerhalb des kognitiven Systems muss dieses nur dann neu programmiert werden, wenn die Montage des zu fertigenden

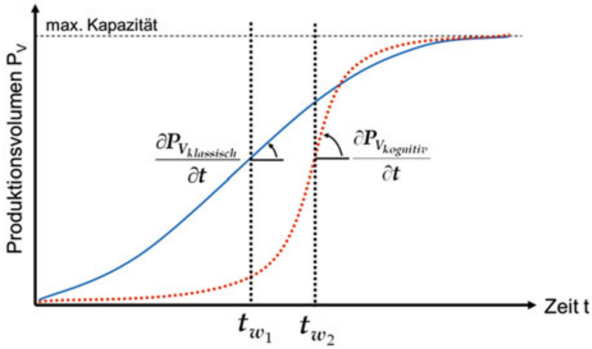


**Abb. 3** Beispiel eines Anlaufprozesses, bei dem die Kennzahl Kbpv eines Produktionssystems größer, aber das Gesamtproduktionsvolumen kleiner ist

Produktes Arbeitsschritte enthält, die vorher nicht im System gespeichert wurden (z. B. bei Verfügbarkeit neuer Werkzeuge). Mit Hilfe der selbstständigen Planung des Montageprozesses und unter den durch den Anwender übergebenen Randbedingungen, müssen keine neuen Arbeitsabläufe programmiert werden. Die adaptive Anpassung der Montagesequenz kann einen Zusammenbau auch unter vorher nicht bekannten Bauteilzuführungen sicherstellen [4]. Dies ist bei einem klassischen Montagesystem nicht der Fall, da derartige Änderungen mit enormem Arbeitsaufwand angepasst werden müssen.

## 2.2 $K_{BPV}$ – *Beschleunigung der Produktionsvolumenzunahme*

Die zweite Kennzahl, *Beschleunigung der Produktionsvolumenzunahme*, bestimmt sich aus dem Vergleich der maximalen Steigerungen des Produktionsvolumens pro Zeiteinheit an der Stelle $t_w$:

$$K_{BPV} = \left( \frac{\frac{\partial P_V}{\partial t}|_{kognitiv}}{\frac{\partial P_V}{\partial t}|_{klassisch}} \right) - 1 \tag{3}$$

Mit

| | |
|---|---|
| $K_{BPV}$ | Kennzahl der Beschleunigung der Produktionsvolumenzunahme |
| $\frac{\partial P_V}{\partial t}\|_{kognitiv}$ | Steigung am Wendepunkt des kognitiven Produktionssystems |
| $\frac{\partial P_V}{\partial t}\|_{klassisch}$ | Steigung am Wendepunkt des klassischen Produktionssystems [6]. |

Für den Fall, dass die Wendepunkte beider Anlauffunktionen $f(t)$ identisch sind, ist die Kennzahl $K_{BPV}$ ausreichend, um die Dominanz eines Produktionssystems zu bestimmen. Falls die Wendepunkte nicht übereinstimmen, kann ein Produktionssystem, das einen steileren Gradienten jedoch zu einem späteren Zeitpunkt aufweist, eventuell ein schlechteres Gesamtproduktionsvolumen besitzen (Abb. 3). Die Zeitpunkte $t_{w_i}$ bezeichnen die Wendepunkte, an denen die jeweiligen Steigungen der Kurven maximal sind.

## 2.3 $K_{SPV}$ – Steigerung des Gesamtproduktionsvolumens

Für diesen Fall muss eine dritte Kennzahl, die *Steigerung des Gesamtproduktionsvolumens*, hinzugezogen werden. Sie berechnet sich durch die Integration über die Anlauffunktion $f(t)$ in einem bestimmten Zeitraum. Durch die Quotientenbildung lässt sich ein direkter Vergleich von kognitiven und klassi-schen Produktionssystemen:

$$K_{SPV} = \frac{\int_{t_0}^{t_{S_1}} f_{kognitiv}(t)dt}{\int_{t_0}^{t_{S_2}} f_{klassisch}(t)dt} \tag{4}$$

Mit

$K_{SPV}$ Kennzahl der Steigerung des Produktionsvolumens
$t_0$ Start der Produktion
$t_{S_i}$ Zeitpunkt der Serienproduktion mit voller Kapazität.

Unter der Voraussetzung, dass das Integral von $f(t) > 0$ ist, ist ein kognitives System einem klassischen überlegen, wenn die Kennzahl einen Wert > 1 annimmt. Die Kennzahl $K_{BPV}$ stellt die notwendige Bedingung für die Überlegenheit eines kognitiven Produktionssystems in der Montage dar, während die Kennzahl KSPV die hinreichende Bedingung für eine Verbesserung ist [6]. Diese Überlegung ist lediglich von Bedeutung, wenn beide Zeitpunkte nur geringfügig voneinander abweichen. Andernfalls ist das „schnellere" Produktionssystem immer zu bevorzugen, da Zeit die kritische Variable in der Ramp-up Phase ist.

## 2.4 $K_{PQ}$ – Planqualität

Die vierte Kennzahl ist die *Planqualität*. Sie bestimmt sich aus der Anzahl an Montageschritten, die erforderlich sind, um ein Produkt zu fertigen. In einem klassischen Montagesystem wird die Sequenz im Vorfeld optimiert und diese dann programmiert. Auch bei der kognitiven Montageplanung der CCU wird das Planungsproblem im Vorfeld gelöst und damit die optimale Montagesequenz gefunden. Diese Planung kann jedoch während der Produktion fortgesetzt werden, d. h., dass das kognitive System während des Prozesses auf veränderte Randbedingungen reagieren und dafür die neue optimale Montagesequenz finden kann [6]. Somit würde die Summe der Kantenkosten entlang des optimalen Pfades innerhalb des Montageplans reduziert. Die Planqualität eines kognitiven Systems ist damit mindestens so gut wie die eines klassischen Montagesystems und kann durch kontinuierliche Fortsetzung der Planung eine Verbesserung und somit geringer Gesamtkosten innerhalb des Montageplans erzielen:

$$K_{PQ} = \sum_{i=0}^{n} K_{i_{klassisch}} - \sum_{i=0}^{m} K_{i_{kognitiv}} \tag{5}$$

Mit

| | |
|---|---|
| $K_{PQ}$ | Kennzahl der Planqualität |
| $n$ | Anzahl der Montageschritte mit klassischem Produktionssystem |
| $m$ | Anzahl der Montageschritte mit kognitivem Produktionssystem |
| $K_{i_{klassisch}}$ | Kosten der optimalen Sequenz mit klassischem System |
| $K_{i_{kognitiv}}$ | Kosten der optimalen Sequenz mit kognitivem System. |

Das kognitive System ist in der Lage, die Montagesequenz je nach verfügbaren Bauteilen anzupassen. Die gefundene optimale Montagesequenz ist unter der Bedingung einer deterministischen Bauteilzuführung bzw. des Vorliegens aller nötigen Bauteile und Baugruppen erstellt worden. Durch die Möglichkeit der dynamischen Allokationen von neuen Kantenkosten innerhalb des Montageplans, kann das kognitive Montagesystem die Sequenz dynamisch anpassen und so die optimale Planqualität in einer dynamischen Umwelt sicherstellen.

## *2.5 Diskussion*

Die vorgestellten Kennzahlen adressieren das Polylemmas der Produktionstechnik und zielen darauf ab, Verbesserungen kognitiver Systeme im Vergleich zu klassischen Produktionssystemen zu identifizieren. Das Ziel des genannten Exzellenzclusters ist die Entwicklung neuer Produktionstheorien sowie deren Validierung. Dabei leisten die Kennzahlen einen entscheidenden Beitrag auf den drei Dimensionen Kosten ($K_{PA}$), Zeit ($K_{BPV}$ und $K_{SPV}$) und Qualität ($K_{PQ}$). Diese Kennzahlen sind wie folgt definiert; Je größer der Wert, desto überlegener das kognitive System im Vergleich zum klassischen. Es wird erwartet, dass $K_{BPV}$ durch die Automatisierung und Beschleunigung der Ramp-up Phase mittels der CCU, steigt. Zudem ist es nicht notwendig, eine intensive Programmierung vor Inbetriebnahme durchzuführen. Stattdessen muss das System mit neuen Produktionsregeln eingelernt werden, um es zu optimieren. Dies kann parallel zum Aufbau der Montagezelle erfolgen, sodass der gesamte Prozess zeitlich vorverlegt werden kann und $K_{SPV}$ ebenso steigt.

Der Vorteil von kognitiven Systemen besteht in ihrer Flexibilität, verschiedene Varianten eines Produktes gleichzeitig in einer Montagezelle zu montieren. Bei der Hinzunahme von weiteren Varianten entstehen im günstigsten Fall keine weiteren Kosten, sodass $K_{PA}$ positiv sein wird. Da Kosten und Zeit voneinander abhängig sind, werden auch $K_{BPV}$ und $K_{SPV}$ steigen. Die Planqualität eines kognitiven Systems ist dabei mindestens so gut wie die eines klassischen Systems ($K_{PA} \geq 0$). Während in heutigen automatisierten Systemen lediglich die zuvor implementierte Montagestrategie umgesetzt wird, kann sich die CCU aufgrund ihrer kognitiven Fähigkeiten selbst während des Prozesses optimieren. Um die Planqualität in einem klassischen System zu steigern, ist die Neuprogrammierung auf Basis menschlichen Lernens erforderlich, was jedoch zu steigendem Aufwand und somit zur Erhöhung der anderen Kennzahlen führt.

Insgesamt sind die Kennzahlen in der Lage, die Überlegenheit kognitiver Systeme (kosteneffizienter, flexibler und robuster) im Vergleich zu klassischen automatisierten Systemen herauszustellen. Somit wird die erreichte Reduzierung des Polylemmas der Produktionstechnik (vgl. Abb. 1) quantifiziert.

## 3 Fazit und Ausblick

Hochlohnländer stehen im Wettbewerb mit Niedriglohnländern und sehen sich dem Polylemma der Produktionstechnik gegenüber, das durch den Einsatz kognitiver Planungssysteme gemindert werden kann. Dafür wurden in diesem Beitrag Kennzahlen vorgestellt, die die Vorzüge im Vergleich zu klassischen Produktionssystemen herausstellen. Diese konzentrieren sich auf die Verbesserungen, die während der Ramp-up Phase durch die Fähigkeit der Selbstoptimierung erreicht werden. Die Herausforderung von Grundlagenforschung, wie die des Exzellenzclusters, umfasst häufig die Überzeugung der Industrie von der Leistungsfähigkeit neuer Lösungen. Allerdings benötigen Unternehmen zuverlässige Aussagen über deren Anwendbarkeit und Wirtschaftlichkeit. Dabei können die entwickelten Kennzahlen eine wichtige Rolle spielen, da sie genau das erforderliche Beweismittel im untersuchten Themengebiet liefern. Während in diesem Beitrag die theoretischen Grundlagen aufgezeigt wurden, müssen zukünftig industrielle Anwendungen durchgeführt und mittels Vergleich der Montage eines Produktes, einschließlich dessen Anlauf, mit dem Einsatz der CCU auf der einen Seite und mit dem klassischen Ansatz auf der anderen Seite untersucht werden. Diese praktische Prüfung muss auf andere kognitive Systeme erweitert werden, um die Übertragbarkeit der Kennzahlen zu demonstrieren.

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# Key Performance Indicators for the Impact of Cognitive Assembly Planning on Ramp-up Process

**Christian Büscher, Eckart Hauck, Daniel Schilberg and Sabina Jeschke**

**Abstract** Within the ramp-up phase of highly automated assembly systems, the planning effort forms a large part of production costs. Due to shortening product lifecycles, changing customer demands and therefore an increasing number of ramp-up processes these costs even rise. So assembly systems should reduce these efforts and simultaneously be flexible for quick adaption to changes in products and their variants. A cognitive interaction system in the field of assembly planning systems is developed within the Cluster of Excellence "Integrative production technology for high-wage countries" at RWTH Aachen University which integrates several cognitive capabilities according to human cognition. This approach combines the advantages of automation with the flexibility of humans. In this paper the main principles of the system's core component – the cognitive control unit – are presented to underline its advantages with respect to traditional assembly systems. Based on this, the actual innovation of this paper is the development of key performance indicators. These refer to the ramp-up process as a main objective of such a system is to minimize the planning effort during ramp-up. The KPIs are also designed to show the impact on the main idea of the Cluster of Excellence in resolving the so-called Polylemma of Production.

**Keywords** Key Performance Indicators · Cognitive Control · Self-Optimization · Assembly Planning

## 1 Introduction

In this paper, a set of key performance indicators (KPI) is discussed describing the impact of a cognitive interaction system on the ramp-up period of highly automated assembly systems. The basis is a cognitive interaction system which is designed within a project of the Cluster of Excellence "Integrative production technology for high-wage countries" at RWTH Aachen University with the objective to plan and

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control an assembly autonomously. The overall objective of the Cluster of Excellence is to ensure the competitive situation of high-wage countries like Germany with respect to high-tech products, particularly in the field of mechanical and plant engineering. Yet these countries are facing increasingly strong competition by low-wage countries. The solution hypothesis derived in the mentioned Cluster of Excellence is seen in the resolution of the so-called Polylemma of Production e. g. by improving the ramp-up process.

The contribution of the project "Cognitive Planning and Control System for Production" is the development of a cognitive interaction system. Cognitive interaction systems in general are characterised by two facts. On the one hand, they comprise cognitive capabilities as mentioned before and on the other hand, they feature an interaction between the technical system and human operators [1]. One of the major challenges of the Polylemma of Production is to increase the efficiency of planning and simultaneously utilise the value stream approach in the domain of assembly which comes along with an improvement of the ramp-up process. The main results are the implementation of a cognitive control unit (CCU) as the key component of the cognitive interaction system and the construction of an assembly cell on the technical side to practically test the functionality of the CCU.

In this context, assembly tasks are a big challenge for planning systems, especially considering uncertain constraints, as implied in this approach. As a result, classic planning approaches have shown to be of little use due to the huge computational complexity. By calculating the complex planning problems prior to the actual assembly, this problem can be bypassed – but current and temporary changes cannot be taken into account. That is why in this project, a hybrid approach of pre- and re-planning of assembly tasks is followed. While the CCU plans and controls the whole assembly process, the operator only executes assembly steps, which cannot be fulfilled by the robots, and intervenes in case of emergency. In this way, the robot control, which is now based on human decision processes, will lead to a better understanding of the behaviour of the technical system and helps automating the ramp-up process.

The crucial point of the CCU is the reduction of planning costs compared to traditional automated assembly systems during ramp-up. This is reached by means of cognitive capabilities with simultaneously increasing the flexibility during the actual assembly process. To quantify this, a set of four KPIs is developed in this paper. These KPIs point out the influence of implementing a cognitive interaction system for assembly planning to the Polylemma of Production and particularly to the ramp-up period within a product development. The ramp-up process – period between completion of product design (pilot series release) and attainment of full capacity – is especially in automated production and assembly systems a planning- and cost-intensive phase. It includes the derivation of an assembly strategy, the design and possibly modelling of the assembly cell and the programming of the robots [2]. Here, the CCU makes an important contribution to minimize these expenses. The new KPIs therefore concentrate on the comparison of production systems with and without cognitive interaction systems while general performance measuring systems for the ramp-up itself already exist [2, 3].

The main contribution of this paper lies in the development and implementation of key performance indicators that can show the impact of cognitive interaction systems system on the ramp-up period of highly automated assembly systems using the example of the cognitive control unit developed within the Cluster of Excellence "Integrative production technology for high-wage countries" at RWTH Aachen University. The remainder of the paper is organized as follows: in the next section the ramp-up period in general and possible improvements of cognitive interaction systems within this step are described. In the first part of Sect. 3, the idea of the Cluster of Excellence is introduced with a focus on the intended influence on production economics in high-wage countries centralised in the Polylemma of Production. Furthermore, the project, in which the presented cognitive interaction system is developed, is introduced. Section 4 is characterised by the presentation of the methodologies and strategies of the cognitive control unit. The new KPIs are presented and discussed in Sects. 5 and 6. The paper concludes in the last section with future research directions.

## 2 General Aspects of the Ramp-up Period

The product development process is divided into two stages (Fig. 1):

- the conceptual design and
- the production.

In the conceptual design stage, at first, the product planning is carried out with accordance to the market factors and the potential market. During the product planning, the process of the product development is already started and since these activities are iterative, they are grouped in a single phase. Furthermore, the joining ability of the single components is analysed in this phase. The product planning represents the transition between the idea for a product and its definition [4]. During the product planning and development, an initial prototype of the product is developed manually or by using a rapid prototyping technique. Thus, a first impression can be gained about the product and its haptic. In this phase, aspects of the assembly are already considered, since it is fatal to the assembly of a product if the individual components do not fit together [5].

As soon as the prototype has reached the desired developmental stage, the pilot series production starts. From this point on, different processes which form the ramp-up period flow simultaneously. The process testing and optimisation start with the pilot series. Within the literature, the pilot series is divided into a pre-series, in which the rejection rates may be higher, and a pilot run, which represents the actual run-up to the production [9]. It ends with the start of the production that is with the actual ramp-up. This includes all activities for planning, managing and implementing the start-up, ranging from product and process development to mass production, including all upstream and downstream processes. The ramp-up phase

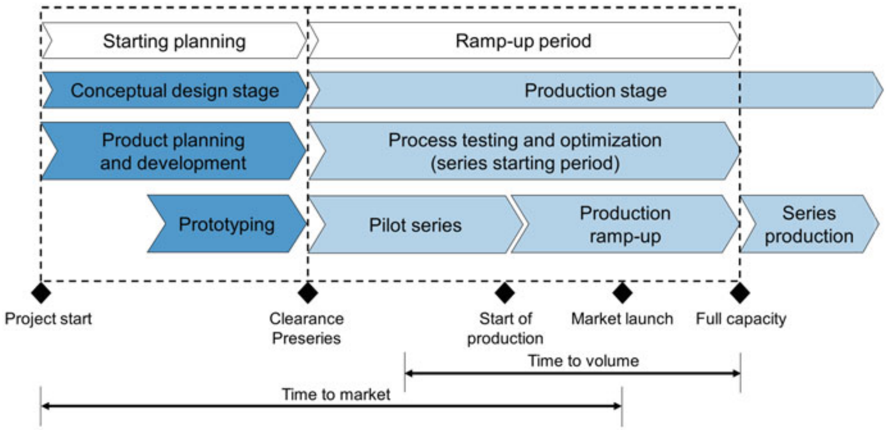



**Fig. 1** Ramp-up period within the product development process (according to [6–8])

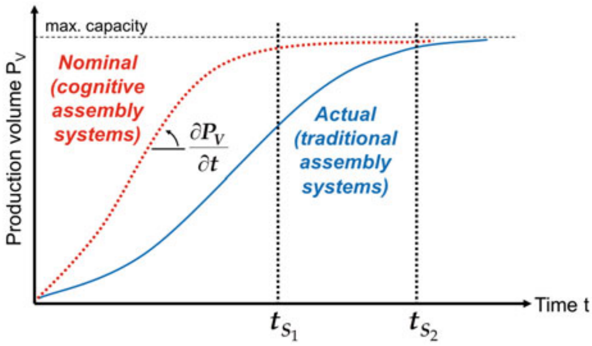
involves the market launch and lasts up to the series production by reaching full capacity [6].

The installation of a cognitive interaction system has particularly influence on the ramp-up process for the assembly of a product. During the conceptual design stage, the effort for the planning of one assembly step in the manufacturing of a product is identical between a production that does not use systems with cognitive capabilities and a production that falls back to a cognitive interaction system. But starting the actual ramp-up with the pilot series, the programming and optimisation of a cognitive interaction system is more complex than the traditional assembly programming (for example through teaching of trajectories). Due to the higher flexibility of cognitive systems, the optimisation, however, can be made more quickly in a later series manufacturing. This advantage can only outweigh the disadvantages of increased complexity in the pilot series if multiple products are assembled on the same production system (utilise economies-of-scope) or a subsequent product change will be made.

Due to the fact that a cognitive interaction system is capable of responding to changing environmental conditions by varying its assembly sequence depending on the requirements by means of self-optimisation, several products can be manufactured in parallel on the same assembly cell [10]. In contrast, traditional programmed systems have to be readjusted for each product and assembly variation. Thereby, cognitive interaction systems can achieve a broadening of the product range without entailing significantly higher costs in the assembly.

This is especially reflected in the ramp-up period of a new product. Figure 2 shows the characteristics of a ramp-up process with the use of cognitive interaction systems within the assembly system and the corresponding phase of a production with traditional assembly systems. The ramp-up period of a production until reaching the capacity limit can be approximated by an S-curve (logistic function). The points

**Fig. 2** Characteristic of the ramp-up period with and without the use of cognitive interaction systems within the assembly system




in time $t_{S_1}$ and $t_{S_2}$ refer to the achievement of maximum series production capacity of each production system [11].
The S-curve is calculated according to the general equation [11]:

$$f(t) = C * \frac{1}{1 + e^{c*(t_i - t)}} \tag{1}$$

With

| | |
|---|---|
| f(t) | ramp-up function |
| C | maximum capacity |
| t | time |
| $t_i$ | time of the inflection point of the ramp-up function |
| c | constant |

This equation has a turning point on the site ti, where the slope of the curve is maximal. At this point, the biggest gain in production volume per time unit is effected, that is $\frac{\partial P_V}{\partial t}|_{t=t_i} = \max$. In the progress of the curve, it is assumed that all optimisation steps within the production system, excluding the assembly step, are identical for both ramp-up curves. In a ramp-up process without the use of a cognitive interaction system, this slope matches the learning curve of operators who participate in the mounting process and optimise the assembly step. In a system containing a cognitive interaction system, this learning effect is enforced by the self-optimisation of the system during the process. That means that such a production system can reach the maximum capacity more quickly (see Fig. 2, left curve).

To concretise these possible advantages of cognitive technical systems within the ramp-up period the next sections present a precise system with the CCU. First of all the idea of the Cluster of Excellence is introduced which builds the basis for the development of this system. Both descriptions are mandatory to follow the creation and discussion of the KPIs in Sects. 5 and 6 in detail.

## 3 Cluster of Excellence "Integrative Production Technology for High-Wage Countries"

The aim of the Cluster of Excellence "Integrative production technology for high-wage countries" at RWTH Aachen University is to assure the production in high-wage countries by developing basics for sustainable production-scientific strategies and theories, as well as the necessity of technological approaches. To reach this objective, production in high-wages countries has to be regarded from different angles of visions and in an integrative manner [12]. Several institutes of RWTH Aachen University, which are dealing with the diversity of production engineering, are united under the Cluster of Excellence.

### *3.1 The Polylemma of Production*

Competitive production engineering is particularly important for high-wage countries such as Germany as other competing countries, for example in Eastern Europe or Asia, have much lower factor costs. The influence of these low-wage countries has a tremendous impact on high-wage countries' economy due to all globalisation tendencies. Two dimensions can be identified within the competition between production companies in high-wage and low-wage countries: the production-orientated economy and the planning-orientated economy [13]. The global production industry is confronted with both dichotomies.

Due to low productive factor cost, low-wage countries' production can compensate possible economic disadvantages such as long process times, factor consumption and process mastering. They predominantly focus on the utilisation of volume effects in production [12]. In contrast, companies in high-wage countries try to exploit the economies-of-scale by the usage of relatively expensive productivity factors. However, while these disadvantages of relatively high unit-costs emerge more and more, companies concentrate on customising, fast adaptations to market needs and the usage of synergy effects within the production of related portfolios (economies-of-scope). In addition, the share of production within the value chain decreases, which in turn leads to a decrease of the realisable economies-of-scale. Furthermore, the escape into sophisticated niche markets is typically not promising [12]. In general, companies in high-wage countries have to position themselves in-between scale and scope [13].

An additional competitive disadvantage for high-wage countries emerges on the planning-oriented economy. Companies often try to optimise processes with sophisticated, investment-intensive planning methods and production systems since processes and production systems do not reach their limit of optimal operating points. This includes a complex ramp-up management to run production close to these optimal operating points. In contrast, companies in low-wage countries implement primarily simple, robust value-stream-oriented process chains and do not concentrate on higher planning activities [12].

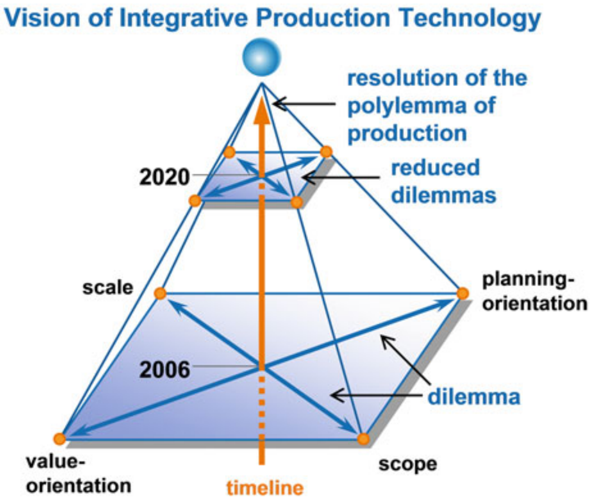



**Fig. 3** The Polylemma of Production [13]

The dichotomy scale vs. scope on the one hand and the dichotomy value- vs. planning-orientation on the other hand are the dilemmas, production industry, especially in high-wage countries, has to face. These dichotomies span the so-called Polylemma of Production as shown in Fig. 3 [13].

A better positioning within this Polylemma of Production is no longer sufficient to achieve sustainable competition advantages for the production in high-wage countries. Therefore the aim of the Cluster of Excellence is to possibly resolve both dichotomies by extending product variability and quality while simultaneously producing at series manufacturing costs [13].

### *3.2 The Project "Cognitive Planning and Control System for Production"*

The challenge of the typical advanced rationalisation of traditional production systems and processes in high-wage countries is the implementation of value stream-orientated approaches with simultaneously increasing planning efficiency. To face this problem, the capability of self-optimisation is required. Self-optimisation allows an optimisation of real production processes without raising preceding planning costs and so optimizing the ramp-up process [10]. Therefore, within the domain "Self-Optimising Production Systems" of the mentioned Cluster of Excellence the focus lies on methods and technologies to enhance cognitive capabilities of production systems as the basis for self-optimisation. New perspectives of manufacturing and assembly systems are opened up by the application of existing knowledge to similar situations or new production cases as the core of self-optimisation [1].

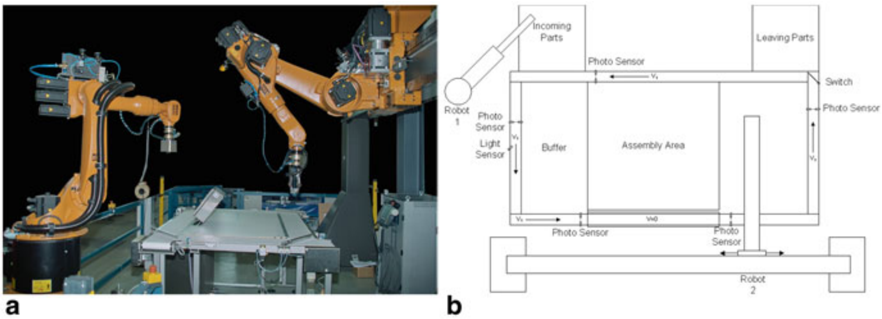



**Fig. 4** Photo and diagram of the robot cell

The technological basis of the promising approach to reduce previous planning efforts by developing a production system that is able to autonomously plan the production during a running process and that could autonomously react to changes in customer demands is a novel architecture of the production cell's numerical control based on a cognitive architecture [14].

A cognitive interaction system with a cognitive planning and control unit (CCU) is developed within the project "Cognitive Planning and Control System for Production" to aim at the automation of the assembly planning process. The basic set-up of the CCU is founded on the architectures that illustrate human cognition. Therefore, a modularly assembled cognitive architecture for a production technology environment including a module to store knowledge and a human-machine-interface is developed as a framework for the implementation of cognitive capabilities [15]. According to human cognition, these artificial cognitive capabilities are perception, reasoning, remembering, planning, decision making, learning and action [16].

The approach is discussed as part of a scenario, which contains an assembly cell with two robots (Fig. 4): one (Robot 2) is only controlled by the CCU [15, 17]; the other one (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. In case that a part is picked up, it will be put into a buffer area or into the assembly area for immediate use. The practical assembly scenario, which also forms the basis of this paper, is a tower of four different coloured Lego bricks (see Fig. 6).

This scenario bases on a random block delivery, which is a specialty of this approach and emphasises the flexibility of such a cognitive interaction system. Handling this kind of uncertainty in the system is a novelty. As a result, extensive material supply timing and planning, as it has to be done e. g. with Just in Sequence, is not necessary any more [18]. Instead the material storing has to be focused but which being cost-intensive than the whole planning problem [19]. Due to this approach, 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. Therefore, a hybrid approach is followed, which bases on state graphs [14].

The project's focus lies on evaluating the concept and methodology of this novel automation approach. To understand the basic ideas of the CCU, the next section will present the underlying assembly strategy including the determinations on which the assembly rules of the CCU are built.

## 4 The Cognitive Control Unit

The main idea of the cognitive control unit is to autonomously plan and control the assembly of a product solely by its CAD description and so help improving the ramp-up. Hence, it will be possible to decrease the planning effort in advance and to increase the flexibility of manufacturing and assembly systems [15]. Therefore several different approaches, which are suitable for the application on planning problems, are of great interest in the field of artificial intelligence. While generic planners like the ones by Hoffmann [20], Castellini [21] and Hoffmann and Brafman [22] are not able to compute any solution within an acceptable time in the field of assembly planning concerning geometrical analysis, other planners are especially designed for assembly planning, e. g. the widely used Archimedes System [23]. To find optimal plans, it uses AND/OR-graphs and an "assembly by disassembly" strategy. The approach of Thomas follows the same strategy, but uses only geometric information of the final product as input [24]. Nevertheless, both approaches are not adequate enough to deal with uncertainty. Another system developed by Zaeh and Wiesbeck [25] follows an approach which is similar to the CCU apart from the fact that it only plans and does not control the assembly. In this field, the CCU is a sophisticated system on the way to self-optimisation.

The CCU is able to take over tasks from an operator, for example repetitive, dangerous and not too complex operations, as it is capable to process procedural knowledge encoded in production rules and to control multiple robots. As knowledge-based behaviour as well as skill-based behaviour cannot be modelled and simulated by the CCU, it will cooperate with the operator on a rule-based level of cognitive control [14, 26]. The task of the CCU consists of the planning and the controlling of the assembly of a product that is described by its CAD data while the assembly actions are executed by the assembly robots. After receiving an accordant description entered by a human operator, the system plans and executes the assembly autonomously by means of a hybrid planner. With regard to the cooperation between the CCU and an operator it is crucial that the human operator understands the assembly plan developed by the CCU. Furthermore, a robot control which is based on human decision processes will lead to a better understanding regarding the behaviour of the technical system which is referred to as cognitive compatibility [1].

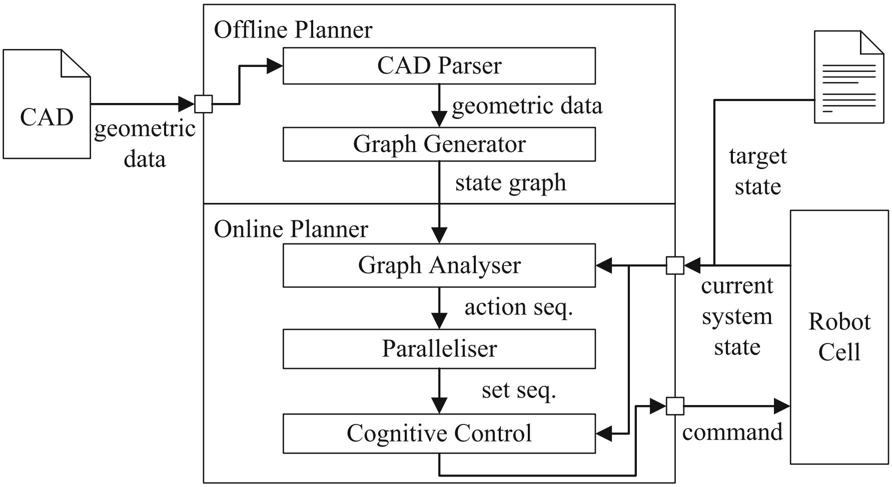



**Fig. 5** Hybrid approach of the CCU

## *4.1 Hybrid Planner*

The planning process of the CCU is separated into two assembly-parts to allow fast reaction times: the Offline Planner, executed prior to the assembly, and the Online Planner, executed in a loop during the assembly (Fig. 5). The Offline Planner allows computation times of up to several hours. Its task is to pre-calculate all feasible assembly sequences – from the single parts to the desired product. The output is a graph representing these sequences. This graph is transmitted to the Online Planner whose computation time must not exceed several seconds. Its task is to map repeatedly the current system state to a state contained in the graph during assembly. In a further step, the Online Planner extracts an assembly sequence that transforms the latest state into a goal state containing the finished product. Thus, the proposed procedure follows a hybrid approach [14].

A solution space for the assembly sequence planning problem is derived during the offline planning phase. As mentioned above, an "assembly by disassembly" strategy is applied to generate an assembly graph, which is first generated as an AND/OR-graph and which is then transformed into a state graph that can be efficiently interpreted during online planning [27]. Therefore, a description of the assembled product's geometry and its constituting parts, possibly enriched with additional mating directions or mating operation specifications, is used. The geometric data is read by the CCU from a CAD file. The main concept of this strategy is a recursive analysis of all possibilities of an assembly or subassembly [28]. Any assembly or subassembly is separated into two further subassemblies until only single parts remain. All related properties of the product's assembly are stored. Additionally, instances can be used to describe functional aspects. This will be relevant if additional data apart from the part geometries is taken into account by the assembly planner [24].

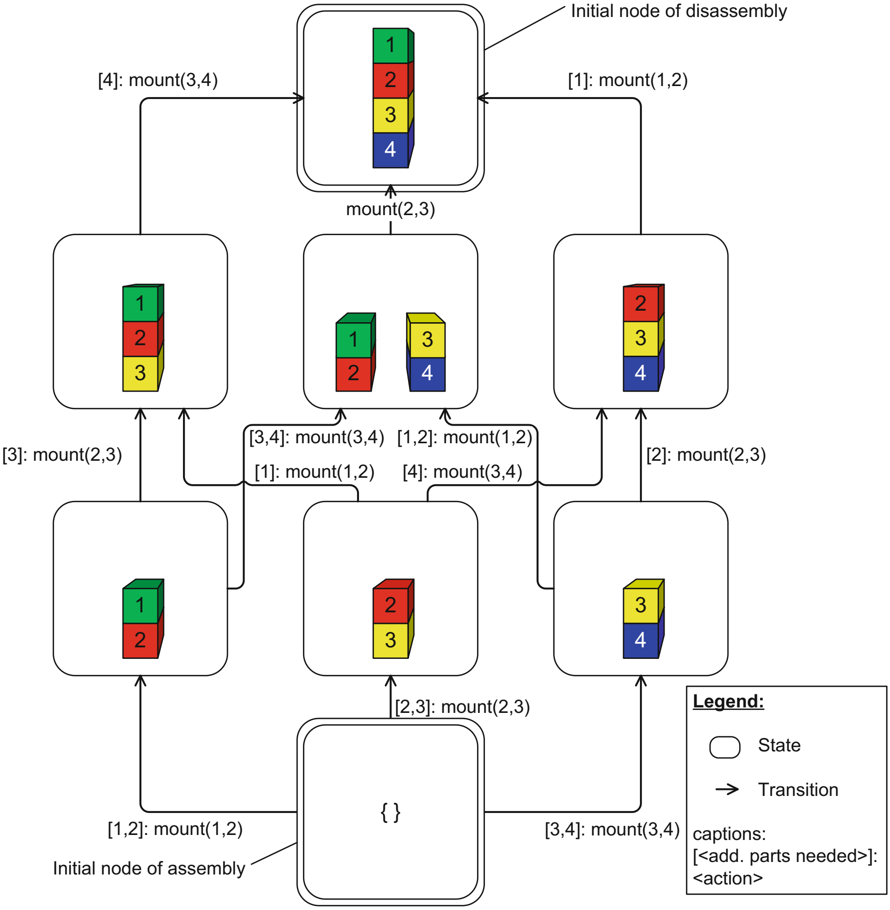



**Fig. 6** Example of a state graph representation

All data of the separation evaluators is stored in the state graph. Figure 6 shows the state graph of the used scenario. The information contains static operation costs and mating operation descriptions for each assembly that might be active during assembly. All transition steps are represented by edges enhanced with the named costs. Each state contains the passive assembly, to which other parts may be added, starting with the empty one at the bottom up to the final product at the top.

The Online Planner derives the assembly plan during the assembly process. It uses the state graph provided by the Offline Planner as well as information about the current robot cell's situation. This approach is similar to the system developed by [25], in which assembly task instructions for a human operator are reactively generated.

The Graph Analyser receives the generated state graph from the offline planning phase and the actual world state describing the current situation of the assembly.

Afterwards, the graph analyser maps this world state onto the matching state contained in the state graph. If this node and the "goal-node" are identical, the assembly has been completed and the process ends. Otherwise, the state graph is updated. Dynamic costs in terms of the availability of necessary parts are assigned to the state graphs edges – in addition to the costs, which already have been assigned to the edges during offline planning [14]. After this procedure, the optimal path to the goal-node is calculated using the A* search algorithm, which represents the optimal assembly plan for the given current situation [29]. This path is tested for parallelization and sent to the Cognitive Control component, which executes the assembly in a further step.

The Cognitive Control component receives the assembly sequence, triggers the accordant robot commands and communicates with the human operator so that the latter can operate e. g. in case of unforeseen changes. This component is based on Soar, a cognitive framework for decision finding that aims on modelling the human decision process [30]. Soar contains several production rules which are stored in the knowledge base. Furthermore, human assembly strategies are developed and implemented in the component to generate a higher degree of machine transparency and to enhance cognitive compatibility [26]. Thus, this component implements the cognitive capability of decision making so that the CCU in general is able to optimise its performance according to different delivered target states.

In this section, the background of the cognitive interaction system with regard to the planning algorithm and the possibilities of decision making within the technical system was described. The next section points out how this approach can help to improve the ramp-up process by defining KPIs for cognitive interaction systems.

## 5 Key Performance Indicators

In order to measure the influence of a cognitive interaction system on the ramp-up process, four key performance indicators were developed. As described in the previous sections, the reduction of planning efforts prior to the assembly is a main objective of cognitive interaction systems like the CCU. This approach enables a faster ramp-up for assembly and thereby comprises at best an increase of production volume during this phase. This has on the one hand a positive effect on the validity of the data generated and beyond that on the quality of the final production process. In addition, the increased flexibility allows not only a static assembly strategy like traditional automated systems, but the possibility to act adaptively within the framework of the generated plan. The four KPIs which show these advantages within the triple constraint (cost, time and quality) are:

- $K_{PE}$ – planning effort (Sect. 5.1)
- $K_{APV}$ – acceleration of production volume growth (Sect. 5.2)
- $K_{IPV}$ – increase of production volume (Sect. 5.3)
- $K_{PQ}$ – plan quality (Sect. 5.4)

The contribution to the ramp-up process and the Polylemma of Production technology is determined by the comparison of the KPIs with and without the use of a cognitive interaction system to control an assembly of components of simple geometry like the scenario described in Sect. 3.2 [11]. All KPIs are defined in a way that the larger the value, the more superior is the cognitive system compared to the traditional one. The turning point where both systems are equal is – depending on the context of the precise KPI – 0 or 1.

## 5.1 Planning Effort

The first KPI, the planning effort, refers to the phase of mounting and initial programming of the cognitive interaction system within an assembly system. The initial filing and maintenance of the knowledge base in a cognitive interaction system represents significantly more work compared to programming a traditional assembly system, for example by teaching the robot. This effort is too high for a production system that is designed only for one product since a traditional assembly system can be programmed very quickly for a specified manufacturing step and this programming has to be adjusted only marginally during production. However, if the assembly system needs to be able to assemble a wide range of products with small batches, a traditional assembly system has to be repeatedly reprogrammed and optimised. In contrast, an assembly system with a cognitive interaction system can be adapted with little effort on a new product.

The key performance indicator $K_{PE}$ is based on Schilberg [31] and is calculated from the sum over $n$ different products to be assembled by the efforts of the programming of the system respectively the creation of the knowledge base and the optimisation of the assembly:

$$K_{PE} = 1 - \left( \frac{\sum_{i=1}^{n} PE_{i_{cognitive}}}{\sum_{i=1}^{n} PE_{i_{traditional}}} \right) \tag{2}$$

With

| | |
|---|---|
| $K_{PE}$ | Key performance indicator of the planning effort |
| $PE_{i_{cognitive}}$ | Planning effort of an assembly system with a cognitive interaction system |
| $PE_{i_{traditional}}$ | Planning effort of a traditional assembly system |

The interval in which the KPI ranges is $[-\infty, +1]$. The extreme value $-\infty$ of the interval will be reached if the planning effort for $PE_{i_{traditional}}$ is arbitrarily small or if $PE_{i_{cognitive}}$ is an arbitrary large value. The other extreme value of 1 will be reached if $PE_{i_{cognitive}}$ is 0 [11].

By the automated assembly planning within the cognitive interaction system, this system only has to be reprogrammed if the assembly of the product to be manufactured contains steps that were not previously stored in the cognitive interaction

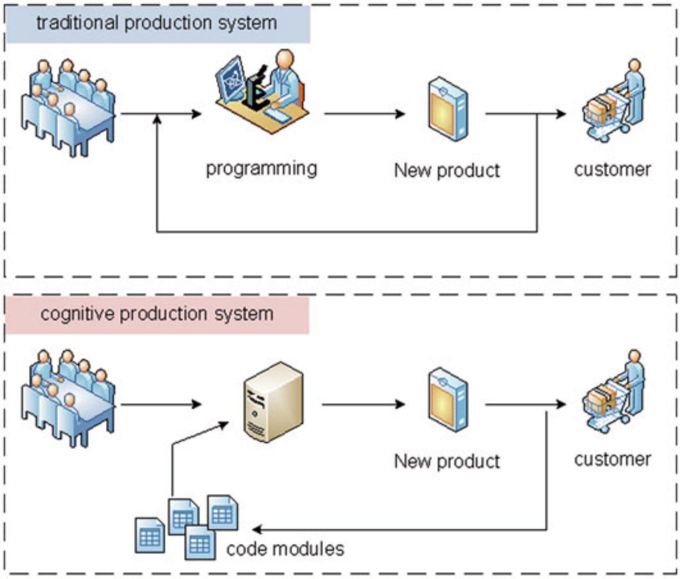



**Fig. 7** Work flow in the programming of the system for a traditional and a cognitive production system

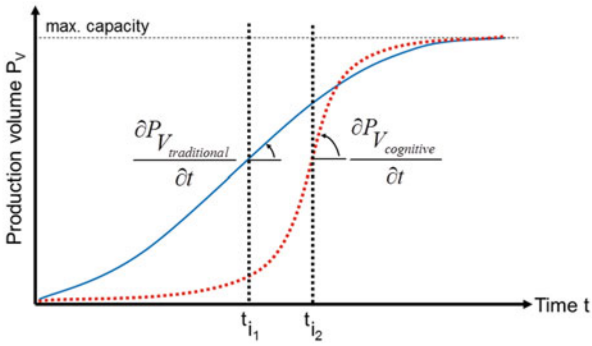
system (for example if a new tool is available, which results in new possible operations). By the independent planning of the assembly process, under constraints which have passed by the operator to the cognitive interaction system, no new operation sequences have to be programmed. The adaptive adjustment of the assembly sequence can even ensure an assembly with a not previously known component supply which is impossible in a traditional assembly system. When a new sequence of steps is to be executed, the assembly system has to be reprogrammed and optimised, which represents a significant amount of work. This does not allow flexible responds of the assembly system to changes in product manufacturing or in the assembly sequence. In Fig. 7, an example of this comparison is illustrated.

## 5.2 *Acceleration of Production Volume Growth*

The second KPI, acceleration of production volume growth, is determined by comparing the maximum increase in production volume per time unit at the site $t_i$. Therefore, the KPI is calculated as:

$$K_{APV} = \left( \frac{\frac{\partial P_V}{\partial t}\big|_{cognitive}}{\frac{\partial P_V}{\partial t}\big|_{traditional}} \right) - 1 \tag{3}$$

**Fig. 8** Example of a ramp-up process where the key performance indicator $K_{APV}$ of a production system is higher, but the total production volume is smaller




With

| | |
|---|---|
| $K_{APV}$ | Key performance indicator for acceleration of production volume growth |
| $\frac{\partial P_V}{\partial t}\vert_{cognitive}$ | Slope at the inflection point of the production system with cognitive interaction systems |
| $\frac{\partial P_V}{\partial t}\vert_{traditional}$ | Slope at the inflection point of the traditional production system |

By forming the quotient, the KPI ranges in the interval $[-1, +\infty]$. A value of $-1$ means that the production volume growth of a production system with cognitive interaction systems is 0, so there is no production. The other extreme value means that the production volume growth with a cognitive interaction system is arbitrarily large respectively the production increase of a traditional production system is 0. This value is never reached because it would mean a discontinuity in the S-curve, which has to be differentiable by definition [11].

In case of a congruence of the inflection points of the ramp-up function f(t) for both production systems, it is sufficient to determine the key performance indicator $K_{APV}$ if one production system dominates the other one. If the two inflection points do not match, it may happen that a production system, which has a steeper gradient but realises this at a significantly later time, possibly has a worse overall production volume. Figure 8 shows such an issue. The points in time $t_{i_1}$ and $t_{i_2}$ describe the inflection points with the maximum slope of the two curves.

## 5.3 *Increase of Production Volume*

In this case, a third KPI, namely the increase of total production volume during ramp-up, should be consulted. It is calculated by integrating over the starting function f(t) in a given period. By the quotient, a direct comparison of production systems with and without cognitive interaction systems can be made. Therefore, the KPI is calculated as:

$$K_{IPV} = \frac{\int_{t_0}^{t_{S_1}} f_{cognitive}(t)dt}{\int_{t_0}^{t_{S_2}} f_{traditional}(t)dt} \tag{4}$$

With

| | |
|---|---|
| $K_{IPV}$ | Key performance indicator of the increase of production volume |
| $t_0$ | Start of production |
| $t_{Si}$ | Time of series production with fully capacity (s. Fig. 2) |

Under the condition that the integral of f(t) > 0, a cognitive system is superior to a traditional system if the KPI takes a value > 1. The key performance indicator $K_{APV}$ represents therefore the necessary condition for the superiority of a production system with cognitive interaction systems in the assembly, while the key performance indicator $K_{IPV}$ is the sufficient condition for a real improvement [11]. This consideration is only meaningful if both times to volume differ from each other marginally. Otherwise the "faster" production system would always be preferred since time is often the critical variable in the ramp-up phase.

## *5.4 Plan Quality*

The fourth KPI is the plan quality, which is borrowed from one criterion for evaluation of planners on the International Planning Competition (IPC) [32]. It is determined from the number of assembly steps required to manufacture a product. In a traditional system, the assembly sequence is either fully optimised and programmed in advance or a heuristic-based optimisation is used by the employee during programming. Depending on the complexity of the product to be assembled, the optimal assembly sequence may not be found in a reasonable time. In the context of this scenario and further scenarios which were analysed within the project, the CCU is able to generate the entire assembly graph in the Offline Planner. At this point no heuristics have to be used but such applications are possible. Thus, this KPI is defined with regard to more complex products where heuristics are relevant.

As described before, in a cognitive interaction system, it may also be necessary to resort to a heuristic to solve the planning problem in a reasonable time in a corresponding product complexity. This planning can be continued during the production, which means that the cognitive interaction system starts with an assembly sequence that was found using a heuristic. Then during the process the system is able to derive a better assembly sequence in parallel by using relaxing heuristics and by conducting a broader search within the AND/OR-graph. If the number of components is below a threshold, all possible decompositions of the AND/OR-graph can be saved and a

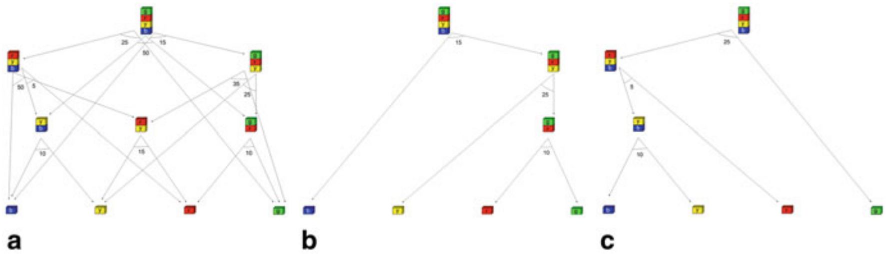


**Fig. 9** Comparison of the plan quality **a** Graph with all possible decompositions with 4 parts and the corresponding edge costs; **b** Assembly sequence with the heuristic that only those nodes with the lowest costs are expanded; **c** Optimal assembly sequence with constant edge cost

guaranteed optimal solution of the planning problem can be found [11]. Figure 9a shows the entire AND/OR-graph of a tower of four Lego bricks. In Fig. 9b, an assembly sequence using a heuristic is shown, in which only those nodes of the graph with the lowest costs are expanded.

The plan quality of the traditional and the cognitive assembly system are identical in this case, provided that the same resources for computing capacity and time exist. However, the cognitive assembly system is able to perform a broader search during the actual assembly and thus to create the optimal assembly plan (Fig. 9c). In this example, this would mean a sum of costs of 40 instead of 50 although the first analysis step of the optimal solution is considerably larger than the one of the heuristic. The plan quality of a cognitive interaction system is thus at least as good as a traditional assembly system and is able to achieve a better plan quality which is ex-pressed by a lower sum of costs in the assembly graph through an on-going continuation of the planning. The KPI is calculated as:

$$K_{PQ} = \sum_{i=0}^{n} C_{i_{traditional}} - \sum_{i=0}^{m} C_{i_{cognitive}} \tag{5}$$

With

| | |
|---|---|
| $K_{PQ}$ | Key performance indicator of the plan quality |
| n | Number of assembly steps with traditional production system |
| m | Number of assembly steps with cognitive interaction system |
| $C_{i_{traditional}}$ | Costs on optimal path with traditional production system |
| $C_{i_{cognitive}}$ | Costs on optimal path with cognitive interaction system. |

Hence, $K_{PQ}$ is never less than zero. In addition, the cognitive interaction system has the ability to adjust the assembly sequence depending on the availability of the single components. The optimal assembly sequence that was found during this process has been created under the terms of a deterministic supply of components respectively the availability of all components and assemblies required. With regard to the possibility of dynamic allocation of the new edge costs within the assembly graph in case of storage of all possible decompositions, the cognitive assembly system is able to adapt the assembly sequence dynamically and to ensure the optimal plan quality in a dynamic environment at any time during assembly.

## 6 Discussion

Against the background of the Polylemma of Production and improving the ramp-up process, the four KPIs presented in Sect. 5 are designed to identify the enhancements by using cognitive interaction systems with respect to traditional production systems. The main objective of the mentioned Cluster of Excellence is to develop new production theories and methods in order to resolve the Polylemma of Production inter alia by improving the ramp-up period and to measure the improvements reached by these innovations. Here, the KPIs provide a significant contribution. They cover the three dimensions costs ($K_{PE}$), time ($K_{APV}$ and $K_{IPV}$) and quality ($K_{PQ}$) and thus represent any expected significant changes by comprising cognitive interaction systems like the CCU.

As pointed out in the last section, the indicators are defined in the following way: the larger the value, the more superior is the cognitive system compared to the traditional one with a turning point by 0 or 1. It is expected that the indicators $K_{APV}$ and $K_{IPV}$ are greater than the turning point. By automating the ramp-up process with the use of the CCU, it speeds up. The production can be ramped up more quickly so that $K_{APV}$ increases. Furthermore, it is not necessary to carry out an intensive programming before the assembly cell can be launched. Instead, new production rules have to be implemented as well as to fill up the knowledge base and teach the system to optimize it. This can be done in parallel to the installation of the assembly cell so that the entire process is moved forward and $K_{IPV}$ increases as well. Thus, a certain dependency exists between the two indicators.

The planning efforts prior to the assembly change in their manner as indicated. Instead of programming the robots, a lot of work in educating the system has to be done when implementing a total new product and its assembly cell. In this case, at the present time, no conclusion can be drawn on the amount of total costs so that $K_{PE}$ can either be positive or negative. The advantage of cognitive interaction systems consists in their flexibility to handle different variants of a product in one assembly cell at the same time. Here, at the best, no additional costs are generated so that $K_{PE}$ is expected to be greater than zero. Since costs and time are interdependent, $K_{APV}$ and $K_{IPV}$ will increase as well.

The plan quality of a cognitive interaction system is, as pointed out in Sect. 5.4, at least as good as a traditional assembly system ($K_{PQ} \geq 0$). While in contemporary automated systems only the previously implemented assembly sequence is followed, the CCU and comparable systems can optimise themselves in the process due to their cognitive capabilities in terms of planning strategies and, if necessary, additionally used heuristics. This superiority increases the more the system is used as its database grows and as it learns from previous tasks for the generation of the plan, which results in a higher quality. The only way the plan quality of the traditional system can increase is a re-programming (see Fig. 7) due to human learning. This results in an increase of the other KPIs based on more efforts and a setback in the ramp-up process.

Overall, the KPIs are capable of representing the impact of the CCU to the ramp-up period of an assembly system. In case that $K_{PE}$ and $K_{PQ}$ point out the superiority of the cognitive interaction system, it is less cost-intensive and more flexible and robust than traditional automated systems. So an improvement of the ramp-up process has been reached and quantified. To prove these assumptions, several business and technology cases will be performed in the next funding period of the Cluster of Excellence while up to now, the assembly cell (see Fig. 4) and the CCU have been implemented and the four KPIs have been developed. These generated data will form the basis for supporting the decision making to apply cognitive systems in industry.

## 7 Conclusion

This paper proposes a set of KPIs which can determine the advantages of a cognitive interaction system in contrast to traditional automated systems to improve the ramp-up period of an assembly system. A precise cognitive interaction system in the domain of assembly planning systems is presented, which is the first self-optimising system in this domain. It comprises several cognitive capabilities implemented in the cognitive control unit (CCU) by a hybrid approach for assembly tasks, which enables robots to decide on their action during assembly autonomously.

To measure the systems' advantages involved, a set of key performance indicators is developed in this paper which can show the impact of this cognitive interaction system. These KPIs concentrate on the main improvements being achieved during the ramp-up phase of the assembly and its construction and sequence planning. The interaction of the four KPIs "planning effort", "acceleration of production volume growth", "increase of production volume" and "plan quality" evaluate the improvements in attaining the final production volume and in reducing the planning effort during ramp-up as well as the enhancement of the quality of the derived plan by means of the self-optimising capability of the CCU. These are developed in the context presented in this paper but designed to highlight the impact of cognitive interaction systems on production economics in general.

With respect to future research, there are plans to fill these KPIs with life, while in this paper the theoretical background for the next step has been set. Therefore, industrial applications are to be performed and analysed by comparing the assembly of a product including its ramp-up with the use of the CCU on the one hand and with the traditional approach on the other hand. Therein, possible weaknesses can be detected and resolved. This practical testing may then be shifted to other cognitive interaction systems to demonstrate the transferability of the set of KPIs. The challenge of fundamental research like the technological innovations developed within this Cluster of Excellence often comprises the persuasion of industry of the high performance of such solutions and the implementation or the launch of a product out of this. However, companies need reliable predictions on the applicability and economic efficiency. At this, the developed KPIs can play a major role as they provide exactly this required evidence in the examined topic.

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# An Introduction to a Transnational Volunteer Notification System Providing Cardiopulmonary Resuscitation for Victims Suffering a Sudden Cardiac Arrest

**Jesko Elsner, Marie-Thérèse Schneiders, Max Haberstroh, Daniel Schilberg and Sabina Jeschke**

**Abstract** While it is always desirable in an emergency to get treatment as soon as possible, there are emergencies that need immediate treatment. In case of Sudden Cardiac Arrest an untreated time interval of only a few minutes usually means the victims' death. Given the delay between an incoming emergency call and the arrival of the emergency medical services at the scene, it is necessary to find an alternative way to provide immediate first aid treatment. One approach for this is the implementation of a Volunteer Notification System – involving laypersons and medically trained volunteers into the emergency medical service, by notifying those potential helpers who can arrive at the scene fast enough to provide the urgently needed measures.

**Keywords** Volunteer Notification System · First Responder · Emergency Medical Services · Sudden Cardiac Arrest · Cardiopulmonary Resuscitation · Telemedicine

## 1 Introduction

Due to the way today's professional emergency medical services (EMS) are organized, victims in need of urgent medical care are facing a lethal problem. Depending on the type of emergency, the time interval between the incoming emergency call and the arrival of the professional helpers at the scene is simply too long. In Bavaria (Germany) for example, a region with good infrastructure and an advanced medical system, reoccurring studies are made every 4 years, in order to analyze the effective time interval local EMS need until arriving at the place of incident. The institute for emergency medicine in Munich (INM) states in a recent study that professional EMS in the area of Bavaria require approximately 9 min until arriving on scene [1]. Furthermore, the study underlines an ongoing increase in this deficit due to a diversity of reasons. The severity of the time deficit generally correlates with the infrastructure a country can provide, resulting in intensification for less advanced

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countries and regions. While most emergencies do not involve an immediate life danger for the victim, in case of a Sudden Cardiac Arrest (SCA) the first minutes are of utter importance. Jan Bahr states that as little as 3 min is most likely enough for victims of SCA to suffer permanent brain damage and Karin Grassl describes within her dissertation that the survival rate after 5 min without treatment is practically zero [2, 3]. Victims suffering SCA are in need of urgent medical care that professional EMS alone cannot always sufficiently provide.

### *1.1 Structure*

The first chapter of this paper describes the medical emergency of a Sudden Cardiac Arrest (SCA) and introduces the basic concept of a Volunteer Notification System (VNS). Starting by identifying and discussing comparable systems, the second chapter focuses on analyzing the technological state-of-the-art of mobile devices and data communication concepts; herby determining the possibilities and restrictions for a VNS approach. The third chapter introduces the current project "EMuRgency". As one focus of the project is the actual implementation of a new VNS, the core components and the corresponding architectural details are being discussed. The fourth and thereby last chapter of this paper introduces the conclusion and shortly discusses a potential generic approach and some optional features.

### *1.2 Sudden Cardiac Arrest*

The human heart has an electrical conduction system that controls the rate and rhythm of the heartbeat. Problems with this electrical system can cause irregular heartbeats called arrhythmias which can lead to Sudden Cardiac Arrest (SCA) - a condition in which the heart suddenly and unexpectedly stops beating. The hereby resulting loss of blood flow prevents the brain and any other vital organ from getting oxygen. Without immediate treatment, the victim dies within minutes. It's a common misconception that SCA is the same as a heart attack, while in reality, they are quite different. SCA is an "electrical problem" that prevents the heart in its whole from functioning, whereas a heart attack occurs when part of the heart's blood supply is reduced or blocked causing the heart muscle to become injured or die [4].

### *1.3 The Basic Concept of a Volunteer Notification System*

One possible solution for offering faster response treatment is the concept of involving volunteers into EMS by implementing a Volunteer Notification System (VNS). A VNS may be defined as an IT system with the following core functionality: by tracking the location of all registered users, the system will be able to notify exactly those potential helpers who are, at the time of the incoming emergency call, geographically close to the place of incident.

This concept of a VNS does not interfere with the local corresponding emergency standard procedures, but can rather be described as an optional add-on to existing EMS; the responsible dispatcher takes the decision if to involve this optional feature. It is important to understand that the potential volunteers are not a replacement for emergency physicians or any professional helper that has been alarmed, but their main purpose is to arrive at the scene fast enough to start Cardiopulmonary Resuscitation (CPR). While there is no exact definition or specification of a VNS yet, it is part of this paper to discuss a potential architecture and distinguish between the core and the optional functionalities of such a system. The technical implementation of an integrated VNS is the focus of the European research project "EMuRgency" which will be described in the Chap. 3.

## 2 State of the Art

### *2.1 Existing Systems with Similar Functionality*

While a diversity of local approaches to implement notification systems exists already, those approaches generally do not have an academic motivation or background. Therefore, publications on the aspect are still rare and the corresponding projects are opening neither their expertise nor the source codes to the public. The only publically available resources are the corresponding application download, some basic usage documentation and a reference document for the Advanced Programming Interface (API) – which merely offers functionality for providing the systems with data [5].

Based on reviews and the appearance in media all over the USA, the PulsePoint Foundation for example offers one of the most advanced software implementations in the field of emergency notifications at the moment [6]. Formerly known as the "Fire Department App" and developed for iOS only, the new version is available under the name "PulsePoint" for Android and iOS [5, 7]. Even though this application is surely great for offering everyday people a possibility to save lives, based on the available documentation, it is a US-only solution without open interfaces. From an academic point of view, it is regrettable that the achieved competences are not shared, which in combination with non-open source codes makes it is nearly impossible to use the project as a base for a scientific work. Furthermore, the implementation approach is rather static, only allowing two types of mobile devices (Android and iOS) as recipients and no other but US specific regulations, legal circumstances and network characteristics are supported. There are a few smaller projects with less impact and publicity, but the problems stay the same.

Beside the difficulties to communicate and rely on more or less closed projects for information flow and depend on their goodwill, the available solutions are implemented as local solutions that cannot easily be adapted to other countries, regions or new legal environments. Fundamental changes are needed in order to use these systems with other than the original parameters and the underlying model itself does not provide a reasonable extension of functionality without making changes to the actual source code itself.

In summary, the currently available systems lack essential interfaces, public tools for gathering and extracting information, an efficient communication flow and basic concepts for extensibility; therefore it seems inevitable to provide a new approach to the topic rather than upgrading an existing one.

### *2.2 Mobile Technologies*

Advances in mobile technologies and the continuous growing popularity for portable digital devices with internet access in nowadays society offer a great starting point for VNS. Without supplying any special devices, a VNS is able to communicate with a huge variety of volunteers by simple using the existing hardware and infrastructure that people own and use anyway. Modern smartphones for example offer a diversity of features that may be used to aid potential helpers in their mission to arrive on scene as early as possible. Some notable built-in features are real time Internet connections, notification options with vibration and sound, photo and video modes, a variety of sensors to enable situation based functionality like a compass, and the fact that actually any modern mobile device is running an operation system (OS) that supports programmatic solutions for individual software.

Based on the basic definition of a VNS, the core functionality of any VNS is the effective localization of the volunteers. The actual localization of mobile devices within a network is a complex matter, while the reliability of the results generally depends on the corresponding network provider and its infrastructure [8]. Different companies and research groups are working on this topic, offering a variety of Advanced Programming Interfaces (API's) with base functionality to access localization data for different types of devices. One of the most advanced examples is Android's Location API, which is part of the Android software platform, developed by Google in conjunction with the Open Handset Alliance (OHA) [9].

The OHA is a consortium of 86 companies, working on developing and advancing open standards for mobile devices. The consortium, led by Google, includes some of the biggest mobile operators like Telekom and Vodafone, as well as some important manufacturers of mobile devices like Samsung and HTC. As an open-source project, the Android source code is publicly available and can be accessed freely; this reflects in a high user acceptance and fast development progress due to contributions from the open source community. The comScore Incorporation recently published a report on the mobile subscriber market for the second quarter of 2012, by which Android is holding an average of more than 60 % market share within the biggest countries of Europe [10]. In a press release from august 2012, the International Data Corporation (IDC) identifies the Android market share at even 68 % worldwide and underlines that these numbers are increasing [11]. Both studies are based on device sales in the corresponding regions and therefore reflect the general tendency within the segment of smartphones and other mobile devices with internet access.

Even though restricting the notification recipients to exclusively smartphones and similar devices running Android is questionable, it seems to be a reasonable decision for rapid prototype development in order to provide an early running system as soon as possible. It must clearly be stated that a limitation of this kind can only be temporary and that a final model of a state-of-the-art VNS has to provide a generic communication approach in order to support a broad variety of different devices. A more detailed discussion on the topic of a possible generic approach will follow in the upcoming sections of this paper.

### *2.3 HTML – the Language of the World Wide Web*

The Hypertext Markup Language (HTML) defines the core language of the World Wide Web (WWW). With the HTML 5 specification becoming the new standard for web interactivity, a lot of features are accessible for programmers to enable client and server technologies to communicate with each other. While a detailed discussion on server push technologies and HTTP requests would clearly exceed the context of this paper, it is important to note that the HTML 5 specification includes full support for so-called WebSockets. WebSockets specify an API as well as a protocol, while the protocol defines the HTTP handshake behavior to switch from an existing HTTP connection to a lower level connection; a so-called WebSocket connection. While a common approach over the last years was to simulate a server push channel over HTTP, a WebSocket connection enables bidirectional communication natively. Referring to the possibilities for the client/server communication within a VNS, the WebSocket approach offers a clean and simple communication concept and enables a generic implementation for any devices complying with the HTML 5 specification [12].

## 3 The EMuRgency Project

The European research project “EMuRgency” has been started in September 2011. Research facilities from Germany, the Netherlands and Belgium are working together on modeling and implementing an integrated Volunteer Notification System (VNS) to gap the time between an incoming emergency call and the arrival of professional helpers at the scene. The name of the project is a composition of the two words “emergency” and “urgent” and refers to urgent help that is needed in case of SCA. The three upper case letters “EMR” identify the regional base of the project; the “Euregio Maas-Rhein” (Eng. “Meuse-Rhine Euroregion”).

### 3.1 Definition of the Term "Volunteers" within a VNS

Before describing the system, its components and the technical details, it needs to be clarified which group of people can actually participate as volunteers within a VNS. A volunteer can be anyone with basic skills in first aid and CPR (Cardiopulmonary Resuscitation) who is willing to help in case of an emergency. It is important to differentiate this definition from the term "first responder" which was defined by US National Highway Transportation Safety Administration as "the first medically trained responder who arrives on scene of an emergency" [13]. While the definition of a first responder includes groups like police officers, firefighters and EMS, it does not include laypersons since those generally do not have medical training. Still, laypersons might be able to provide the needed measures in order to help victims of SCA and thus should be included as potential helpers within a VNS. Within the EMuRgency project, the term "volunteer" is referring to any potential helper, medically trained or not, willing to aid other people in an ongoing emergency.

### 3.2 Integration Between VNS and Professional EMS

Whenever an incident is reported to an emergency dispatch center that might involve SCA, the dispatchers will do what they normally do: send professional help - but optionally also invoke the VNS. It is important to stress that the VNS, at this time of development and based on the way EMS is organized today, is a merely optional feature. This means that the responsible dispatcher may or may not involve the VNS, depending on their analysis of the case and personal motivation. In order for the optional integration to be achieved, the VNS has to provide a user-interface where the dispatcher can initiate a case by forwarding its exact location and some optional information to the system. During SCA, time is of utter importance, so this user-interface has to be as simple and efficient as possible.

Recent interviews were made within the project in order to determine the acceptance and motivation of the dispatchers to integrate a VNS within the general workflow; Even though all the interviewed dispatchers agreed on a potential benefit, it became rather clear that the general acceptance of new systems seems to directly correlate with the extra work that is involved in order to use it. Taking into account the discussed optionality and the still early stage of development within the project, a manual integration will be the starting point towards involving the VNS within the professional EMS workflow. The implementation of an integrated system that gets activated fully automated during a reported emergency is surely desirable, but requires detailed collaboration with the corresponding software providers. Details on this topic are will be addressed in future papers.

### 3.3 How to Determine the Relevant Volunteers in an Ongoing Emergency

As soon as the system receives information on a new emergency, no matter if automated or manually initialized from the dispatcher, the VNS will determine possible volunteers in the closer vicinity of the incident and immediately inform those in walking distance of the ongoing emergency. In order for this to be possible with minimum time effort, the system needs to be "aware" of all potential volunteer locations at the time of the incoming emergency call. This awareness can be achieved by making all connected clients publish their locations to the server in pre-determined time intervals, rather than forcing the server to request all client locations at once not until they are actually needed.

Before notifying any potential helper, a reasonable maximum distance between a volunteer and the incident has to be determined. Only volunteers located within the maximum distance will be considered potential helpers in an on-going notification. The distance that an individual person can travel within - let's say - 5 min depends on many different parameters. An older person, for example, might walk slower than a younger person, while some people are simply in a better shape than others, no matter the age. Due to a great variety of individual parameters influencing a proper notification radius, a suitable solution to begin with, is creating a personalized profile setting; giving any registered volunteer the option to define an individual notification distance by configuring the appropriate parameter in their user profile. To maintain a realistic range, the maximum distance a user can set is limited to 1 km at the moment. Within the project, this functionality is implemented by using a public accessible browser based Web Application; accessing the corresponding URL, new users can register and/or edit their profile settings online. From the technical point of view, this Web Application is a frontend for accessing database functionality on the server.

### 3.4 Webservices

In order to enable external sources, for example mobile clients or applications from project partners, to access specific functions on the server, a different approach is needed. Specific APIs provide mobile clients the necessary functions in order to communicate with the VNS without having to access a web browser. The same approach can offer project partners an interface for integrating alternative ways of volunteer registration into the main system. Commonly used solutions for offering a limited scope of functionality to external clients are are so called Webservices or more specific, REST based Web APIs [14]. By implementing Webservices, a predefined set of functions will become globally available; different devices will be able to communicate with each other over a given network infrastructure; like for example, the World Wide Web.

## 3.5 The Messaging Architecture

At the time of writing, a running prototype of the VNS is available already. The upcoming section will introduce the used messaging architecture and describe the essential components implemented for the different types of communication.

As long as a client is not involved in an ongoing case, the main communication that occurs between the mobile clients and the server is a client-to-server location publishing that automatically gets invoked in a predefined time interval. While a simple implementation approach for this is a common HTTP POST method, the push communication used to send data from the server to a specific client is an entirely different matter. The World Wide Web (WWW) was originally not intended to support bidirectional communication and therefore does not include the corresponding specifications or protocols. With HTML 5 introducing the WebSocket JavaScript interface, a native solution for bidirectional communication is available. Once a WebSocket connection has been established between client and server, instant data communication becomes possible between both sides without explicitly having to deal with technical differences. Based on this kind of real time connectivity, a variety of different features can be implemented, including chat channels for notified helpers and live camera streaming from the place of incident. A short discussion on optional features in general will follow in the outlook section of this paper.

Even though real time connectivity with WebSockets is a promising approach for implementing specific functionalities, having hundreds or thousands of idle clients permanently connected to the system is definitely not a suitable solution. An increased energy consumption of the mobile clients and a possible server overload due to an increasing number of connected clients are the two main reasons for this. Besides, when not involved in an ongoing emergency, only two types of messages are actually exchanged: firstly the location updates that occur every couple of minutes and are sent from client to server, and secondly the event data that is sent from server to client in order to update the main information view and to display upcoming events, training-courses etc. Since HTTP requests generally include a response-content, the message flow for general information and event data has been implemented as a response to an occurred location update and thus does neither need any special connectivity nor an additional request. It is common practice to restrict HTTP get requests to merely read-only operations and implement any request that modifies data on the server as HTTP post. The main difference between these two types of requests is that within an HTTP get request, the key/value pairs are specified in the URL, whereas in an HTTP post request, the key/value pairs are sent after the headers, as part of the request itself.

Analyzing the base functionalities, there is one type of message that cannot wait for the next "location publish" in order to be sent as a reply from server to client, but instead needs to be send instantly; a new case notification message. This message initiates a new case on the server and alarms any potential helper in walking distance to the emergency; the message needs to arrive on the client with the smallest delay possible. In order to push messages from a server to a mobile client, different cloud

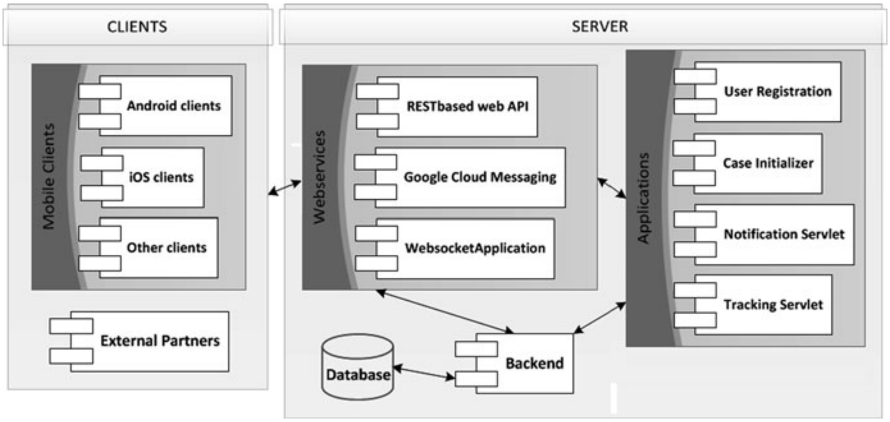


**Fig. 1** Core components of the EMuRgency VNS

messaging solutions are available but generally represent very individual solutions that only work for specific devices or operation systems. The Google Cloud Messaging for Android (GCM) for example is a specific solution to send data from a server to an Android application.

To summarize the messaging architecture at this point of development, HTTP post requests are implemented for client-to-server location updates; the response content of the is then processed in order to send event data from the server back to the client; new cases are initialized by using device specific APIs in order to push notification messages from the server to the mobile clients; and a real time WebSocket communication gets initialized on a new case event for all notified volunteers.

### *3.6 An Integrated VNS Platform*

As a scientific project with partners from both technical and sociological research fields, the project is focusing on many more aspects than a simple technical approach for a notification system. Users of the system will be informed on ongoing events or urgent news and since a common interest level of registered people can be implied, communication channels for exchanging know-how and general information are being implemented. A real-time information flow regarding the aspects of first aid and CPR is extending the core notification functionality. While also developing concepts on raising public awareness on SCA, educational content is displayed at frequently used public places; and if in digital form, the streamed content will be enriched or synchronized with data from the VNS. Furthermore, in order to receive substantial scientific results and to determine the potential benefit of a VNS, corresponding reporting and analyzing features are being designed. Open interfaces will supply options for non-project members to change or extend functionalities. Although details on the generic approach and corresponding concepts for an open architecture are not yet fully developed, an integrated VNS platform will combine the different research topics with the diversity of requirements that are to fulfill.

### 3.7 Regional Differences for Involving Laypersons into Professional EMS

It is important to understand the actual role of an occurring registration and the resulting implications on the system and the user. A newly registered user for example, obviously wants to help, but comparing different countries, potential differences between the way that laypersons are legally allowed to be integrated into EMS, must be considered [15]. Some regions for example might not allow the integration of laypersons in EMS at all; and is a layperson with first aid skills but without corresponding certificates still a layperson? While those questions will not be discussed further within this paper, expert legal advices for different countries are contracted, in order to validate this matter. The direct implication concerning the VNS is that a new user by default will be "unconfirmed" and will not be considered a potential volunteer until "confirmed"; the confirmation process on the other hand is implemented in a separate administrative component, whereas the final details of this component are not yet fully worked out.

### 3.8 An Overview of the Primary Components within a VNS

Within the past sections of this paper, the core components of a VNS have been shortly introduced in their corresponding context. Figure 1 shows an overview of these components while the following paragraph will give some additional information on how they have been implemented.

1. *User Registration*: Implemented as web application, this component offers base functionality for new users to register to the system; existing profiles can be edited and specific settings can be configured by the user – one example for a user specific setting is the notification radius.
2. *Case Initializer*: This application constitutes the actual data provider for new emergencies until more automated concepts are available. Intended for dispatchers only, this web application provides the possibility to manually initiate a new case by providing general information on an ongoing emergency and the corresponding unique location, as pair of latitude and longitude. In order to supply a user friendly interface, the location itself is automatically calculated as an approximation for a given address. This component demonstrates the first approach towards supplying the actual notification system with case data and is implemented as a JavaScript application embedded within a servlet.

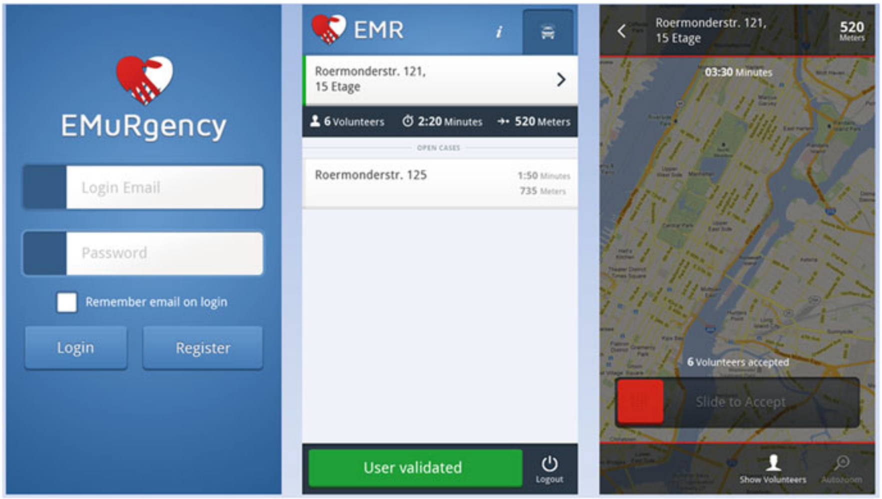


**Fig. 2** The mobile client application (android version)

3. *Server-side applications*: This component bundles the server-side functionalities of tracking and localizing the volunteers. Furthermore, the Case-Initializer is part of this component in order to provide fastest response times when invoking new emergency events.
4. *Backend*: The Backend represents the interface for persisting data and provides functions to enable communication between the database and other system components. Moreover, to ensure a consistent data usage within the system, all referenced data models and structures are defined within this component.
5. *Webservices*: Combining the REST based Web API, Websockets and client specific push technologies like Google Cloud Messaging, this component actually represents an intermediate communication layer; providing predefined functions for external modules and other clients to exchange data with the server.

## 4 Conclusion and Outlook

During the project, sociological and technical aspects are being combined. Country-specific differences in a variety of discussed parameters have been balanced against each other and are being implemented into an integrated VNS platform. Many fundamental difficulties were identified within the past sections of this paper whereas an advanced prototype of the software is available already - Fig. 2 shows screenshots of the android client application. While this prototype implements the essential components introduced in Chap. 3 and enables base notification functionality for nearby volunteers, there are several potentially valuable features being discussed within the project at the moment.

## 4.1 Potential Future Features

The integration of chat channel functionality, enabling direct communication between the dispatcher and all volunteers who accepted a specific case, is one reasonable feature. By using the discussed advantages of a platform independent WebSocket connection, dispatchers will be able to exchange information with volunteers in real-time. Furthermore, status updates and newly received case details can instantly be broadcasted to all relevant receivers.

Another feature is the integration of existing applications or services that provide information on nearby automated external defibrillators (AEDs). Although the time critical aspect of CPR is the main concern for the first volunteer who arrives on scene, it can prove useful for further helpers, to have reliable information on nearby AEDs devices. There are multiple scenarios in which the use of game design elements (gamification) within a VNS can be used to influence the user behavior; the adoption of a score system for attended courses or participated cases is one example. The general idea of gamification elements is to increase the user acceptance and motivation, whereas a sensible consideration is needed in order not to distract attention from the main topic. Since modern smartphones and many other portable devices offer build-in functionality for photos and videos, a real-time media streaming from the place of incident is another possible feature with high benefit. The integration of telemedical concepts becomes possible and thereby enables an approach of professional helpers using their expertise to analyze the streamed data, in order to aid the volunteers at the scene with valuable information.

## 4.2 Specification of a VNS and Future Development

Within this paper, the basic concept of a VNS has been described and both essential and optional components have been discussed. Since many parameters are not yet fully determined and legal issues are still being discussed, there is no formal specification of a VNS at this stage of development. Diverse legal aspects still need to be cleared and options for integrating the system into the professional EMS workflow are being negotiated. Maintaining a highly agile programming approach will assure a continuous development and a fast integration of subsystems, adjustments and new requirements. The research focus for the upcoming 2 years will be the development and implementation of new concepts to enable a generic integration of heterogeneous environments and devices. Architectural cloud approaches will be analyzed and tested, while the integration of the different partners and their corresponding research topics will form into a complex VNS platform.

**Acknowledgements** This paper is based on work done in the INTERREG IVa project EMuRgency (www.emurgency.eu). The project is partially financed through the European Regional Development Fund (ERDF) and co-financed by several regions of the Meuse-Rhine Euroregion and partners of the EMuRgency consortium.

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# Determination of the Relevant First Aiders within a Volunteer Notification System

**Jesko Elsner, Marie-Thérèse Schneiders, Daniel Schilberg and Sabina Jeschke**

**Abstract** During a sudden cardiac arrest (SCA), an untreated time interval of only a few minutes usually means the victims' death. While professional emergency medical services (EMS) are working on shortening the time needed for arriving on scene, there are parameters that limit potential performance increases regarding this topic; e. g. current traffic, the travel distance and the delay between an incoming emergency call and the march out of the professional helpers. Given this premise, it is necessary to find alternative ways for providing immediate first aid treatment to victims suffering SCA. One approach is the implementation of a Volunteer Notification System (VNS) – integrating laypersons and medically trained volunteers into the EMS, by notifying those potential helpers who are, at the time of incident, close to the scene. Whereas the term "close" is suitable for describing the general concept of a VNS, a social valuable system implementation requires an algorithm that analyses and determines which volunteers are to be alarmed. False or unnecessary notifications might have a negative effect on the user acceptance or system performance, whereas not alarming potential helpers who are actually close enough can greatly decrease the system's value. While the actual distance is an important parameter to be considered, it does not necessarily determine the time of arrival at the scene. Due to possible obstacles, the beeline calculation obviously does not offer a suitable background for estimating the traveling time; but even considering up-to-date roadmap material in order to calculate the shortest way does not provide sufficient information without some assumptions. Thus, the type of movement, the physical performance of a volunteer and the traffic situation directly influence those calculations. Furthermore, limiting the relevant decision parameters to merely distance seems inadequate and secondary criteria apply; e. g. medical expertise, knowledge of the area or general engagement. In addition to giving a brief overview to the "EMuRgency" project, this paper will introduce the main criteria for determining the relevant volunteers within an ongoing emergency scenario.

**Keywords** Notification-System · Emergency-Medical-Services · Telemedicine · First-Aid

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# 1 Introduction

The sudden cardiac arrest (SCA) is a medical condition that demands immediate treatment of the victims. Only a few minutes without treatment usually mean the victims' death; Jan Bahr states that an untreated time interval of only three minutes is most likely enough for victims of SCA to suffer permanent brain damage, whereas Karin Grassl describes within her dissertation that the chances of survival after 5 min without treatment are practically zero [1, 2]. Even in highly developed regions, e. g. Bavaria in Germany, emergency medical services (EMS) need in average about seven minutes to arrive on scene [3]; as a possible solution for this problem, the research project "EMuRgency" is implementing a volunteer notification system in order to gap the untreated time interval by involving laypersons and medically trained volunteers into the chain of action of an ongoing emergency [4]. The general idea is to notify and guide those potential helpers, who are at the time of the incoming emergency call, close enough to the case of incident to provide Cardiopulmonary Resuscitation (CPR) to the victim and therefor gap the time until the professional EMS arrive on scene. The different parameters and the decision process, determining which volunteers are to be alarmed, are introduced within this paper.

# 2 Methodology

The actual decision process is influenced by different criteria and a variety of available data on each potential volunteer; this data is either statically available or dynamically collected within the system and then taken into consideration, using the criteria, in order to create a set of results, the decision. The following three categories represent the different types of data available within a volunteer notification system. The first category of data is requested during the actual registration of a new volunteer; the medical competence level, the contact data and personal details like the birthdate are some examples. This data represents a static layer of information; the content of this information is unlikely to change and potential changes are generally not requested by the system but instead triggered by the volunteer – e. g. supplying new certificates of medical training or changing the address. The second category of data is characterized by dynamic data and actively collected by the system. The actual location of a volunteer, represented by a combination of latitude, longitude and altitude, or an available acceleration index on a mobile client, are some examples for frequently changing data that is frequently published to the system. The third category is represented by data that is generated by the system itself; while the process of generating and the underlying system logic is not yet fully defined, the general approach is to process the data from category one and two by using methods and concepts of artificial intelligence (AI) or data mining in order to create new datasets. The creation of abstracted behavior patterns or route approximations based on available historical location values of an individual volunteer, are two examples. As shown in Fig. 1 the three identified types of data are building the input base for

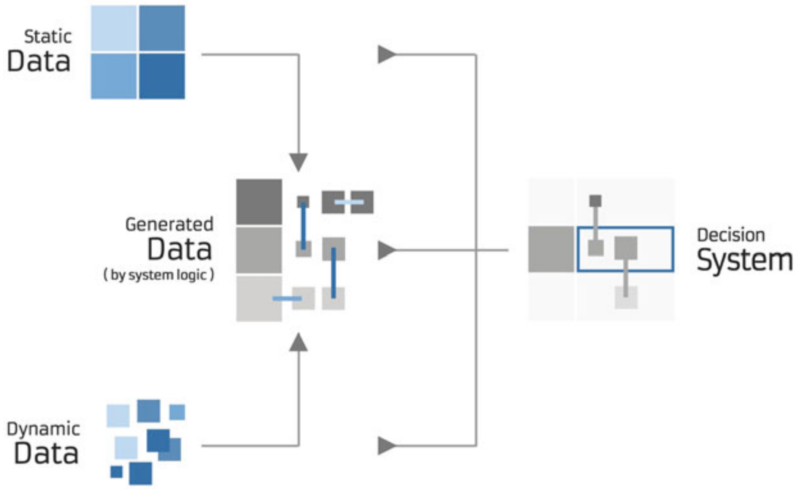


**Fig. 1** Types of data within a VNS

the actual decision system, whereas the final output will be the list of volunteers to be considered. With the input data identified and the result specification defined, the actual decision process is going to be discussed now.

## 3 Decision System

The term decision implies the choice between different options, which have to fulfill specific criteria in order to be considered. With different types of data available, a decision has to evaluate the relative importance of each of them [5]; this evaluation must not be constant but instead occur frequently, adjusting over time, depending on some kind of measurement for the quality of past decisions. Whereas the basic data (static and/or dynamic) will result in a first set of possible volunteers within the decision process, an additional set of volunteers will be selected when processing the generated data and invoking the implemented system AI. Without discussing in detail the requirements of mathematical decision optimization and artificial learning, an AI based approach on volunteer determination will therefor provide an enriched set of possible helpers. The exact composition of the final list is again matter of logic and must not be predetermined, meaning that the decision system will adjust the ratio of assumed candidates and those, determined by "facts", over time, depending on the mathematical quality of the systems' past decisions.

## 4 Conclusion and Outlook

In order to determine the relevant volunteers in an ongoing emergency, a variety of data needs to be considered. This data can be clustered into different categories, depending on its more static or dynamic nature. Available data is furthermore processed by system logic in order to generate new data and enable history based assumptions and different concepts of AI. Whereas this paper has introduced the main concept and idea of an AI driven decision system for determining the relevant volunteers within a VNS, the actual development and implementation is part of the current research focus within the "EMuRgency" project and will be addresses in future publications.

**Acknowledgements** This paper is based on work done within the INTERREG IVa project EMuRgency (www.emurgency.eu). The project is partially financed through the European Regional Development Fund (ERDF) and co-financed by several regions of the Meuse-Rhine Euroregion and partners of the EMuRgency consortium.

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# Prescient Profiling – AI Driven Volunteer Selection within a Volunteer Notification System

**Jesko Elsner, Philipp Meisen, Daniel Ewert, Daniel Schilberg and Sabina Jeschke**

**Abstract** A volunteer notification system (VNS) is a promising approach to integrate laypersons into emergency medical services (EMS). In case of a medical emergency, a VNS will alarm those potential helpers who can arrive on scene fast enough to provide the most urgent measures until the professional helpers arrive at the victim. Whereas the basic requirements and criteria of a VNS have been discussed in recent publications, this paper will focus on the actual volunteer selection process and the underlying concept of Prescient Profiling. By using concepts of artificial intelligence, the available data is processed in order to generate an abstract digital representation of a volunteer and further enhanced to produce individual user profiles. These profiles will enable predictions on future decisions and the identification of behavioral patterns within the pool of volunteers. The goal is to provide an efficient algorithm for determining a highly sophisticated set of relevant volunteers for an ongoing medical emergency.

**Keywords** Volunteer Notification System · First Responder · Emergency Medical Services · Profiling · Artificial Intelligence

## 1 Introduction

As stated within a recent study by the clinical center of the university Munich [1], the average arrival time for emergency medical services (EMS) on scene in Germany is about 9 min. Whereas most medical emergencies do not involve an immediate life danger for the victim, during a sudden cardiac arrest (SCA) the first minutes are of utter importance. The probability of permanent brain damage increases with every minute and a time interval of more than 5 min without treatment will most likely result in the death of the victim [2, 3]. The severity of the time deficit generally correlates with the infrastructure a country can provide, resulting in intensification for less advanced countries.

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One possible approach to provide the most urgent medical measures before the professional EMS arrive on scene is the implementation of a Volunteer Notification System (VNS) as discussed in [4]. The basic concept of a VNS is the integration of laymen and medical trained volunteers into the EMS by notifying those potential helpers who are, at the time of incident, “close” to the victim. Whereas the term “close” is suitable for describing the general idea, the actual process of selecting the relevant volunteers within an ongoing medical emergency requires, due to possible obstacles as e. g., rivers, traffic jams, or alternative transportation means, a sophisticated algorithm in order to ensure the best possible set of potential volunteers at any given time. Artificial intelligence (AI) offers a variety of methods in the area of problem solving [5] and for implementing self-learning systems [6] aiming to increase the quality of decisions by adaption over time. The possibilities of AI driven system within the scope of a VNS will be introduced within this paper.

The remainder of this paper is organized as follows. The difference between a simple and an intelligent volunteer selection will be discussed in Sect. 2, whereas Sect. 3 will highlight the necessity of an intelligent approach by describing some non-trivial decision scenarios in which simple selection algorithms will provide flawed or inaccurate results. Section 4 will therefor introduce the basic concept of (prescient) profiling within this domain as a suitable approach to enable an AI driven volunteer selection. Further research perspectives are discussed in Sect. 5.

## 2 Volunteer Selection

In case of an incoming emergency call, the responsible dispatcher will alert the professional EMS and – in case a cardiac arrest or any type of emergency that requires immediate treatment is suspected – trigger the forwarding of the information into the notification system [4]. The VNS will now decide which volunteers are to be alarmed. In order to prevent unnecessary notifications – hence, notifications that will immediately appear irrelevant to its recipient or notifications alarming volunteers without any plausible chance of reaching the victim in time – an efficient selection algorithm is required [7]. This algorithm has to forecast the approximate arrival time of an individual volunteer at the scene of the incident.

### *2.1 Simple Volunteer Selection*

A simple solution for selecting volunteers is the implementation of a notification radius, defining a maximum distance around the place of incident and alarming those volunteers who are within this radius. This approach will provide a set of helpers who are geographically close to the victim, but will they also arrive on scene faster than potential helpers outside the notification radius? To forecast an individual arrival time, more information is required on both, the volunteer and the environmental details affecting her at the moment.

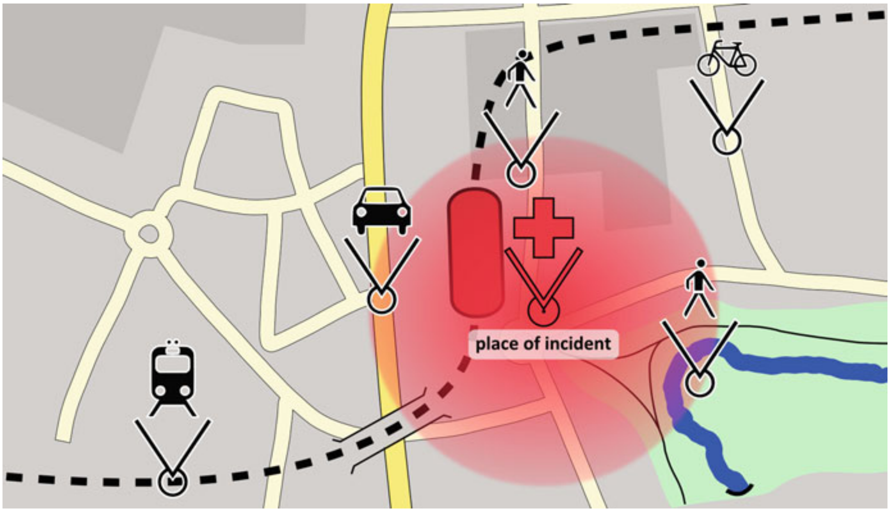


**Fig. 1** Non-trivial volunteer selection

### *2.2 Intelligent Volunteer Selection*

Whilst the actual distance is an important parameter to be considered when deciding if a volunteer should be notified or not, it does not necessarily determine the volunteers' time of arrival at the scene. Due to impassable obstacles (e. g., highways or rivers), the beeline calculation does not offer a suitable background for estimating the arrival time, but even the consideration of up to date map material – like so enabling a shortest way calculation – will not provide sufficient information without additional assumptions.

Thus, the type of movement, the physical performance of a volunteer and the current traffic situation, all have a direct influence on the approximate traveling time and thereby on the time of arrival. Furthermore, limiting the relevant decision parameters to merely distance or traveling time appears inadequate and secondary criteria apply; e. g., the potential volunteers' medical expertise, her individual knowledge of the area and the current situation this volunteer is involved in. An efficient algorithm hence has to consider a broad variety of available information on each individual volunteer in order to generate a reliable set of potential helpers [7, 8].

## 3 Scenarios

The necessity of an intelligent volunteer selection is demonstrated by multiple non-trivial decision scenarios, as illustrated in Fig. 1. The place of incident is close to a railway station (the red bar located on the railway tracks). Leaving heuristics aside, implying to have only five volunteers in total, the most promising of these are to be notified. The use of a simple volunteer selection – as introduced in Sect. 2 – will result in the following set of volunteers (as marked within the red area) that will be alarmed:

- the pedestrian just north of the incident,
- the volunteer in the car (on the highway), and
- the pedestrian in the park (close to the river).

An intelligent volunteer selection will demand further information on each potential candidate than just her current location. The following section gives a short discussion on each single volunteer and the required additional information to decide reliable if the volunteer should be notified or not:

1. *The pedestrian just North of the incident* is geographically the closest volunteer. A straight road connection and no obvious obstacles result in minimal requirements on travel speed or physical performance. This candidate appears a solid choice no matter further assumptions, but eventual circumstances could prevent her from arriving in time, e. g. she might be traveling with her children which she picked up a few minutes ago; just like she does every day at this hour.
2. *The volunteer in the car* is the second closest, but should she be alarmed? Depending on the direction the car is driving and the distance to the next highway exit, this volunteer will most likely have no option to arrive on scene in time.
3. *The pedestrian in the park* is blocked by a river. This volunteer will only arrive in time when the next bridge is within reach. Furthermore, with the park being a green zone with limited map material available, it might only have a single exit that is far away.
4. *The volunteer riding the bicycle* is outside the notification radius, but due to traveling speed and possible short-cuts, she might arrive on scene fast. Parameters like one-way roads or uphill/downhill will influence the arrival time but generally she appears a good choice for notification and compared to a car with the same distance, she will not require a parking place and isn't slowed down by high traffic (which occurs more often around stations).
5. *The last volunteer (in the train)* appears to be far away, but assuming that the train rides in the right direction and will also stop at the next railway station, she might arrive on scene earlier than any of the other volunteers.

Within the illustrated scenarios, the notification radius resulted in a set of three volunteers, from which probably only one has a realistic chance to arrive at the victim in time. Moreover, potentially highly valuable volunteers have not been considered for notification. The given examples are just a small selection of possible scenarios in which no simple answer on if to alarm a specific volunteer exists.

In order to determine the best possible set of volunteers for an ongoing medical emergency, an efficient selection algorithm is required which postulates the availability of a complex knowledge base. A variety of parameters is to be collected, processed and evaluated, forming the digital profile of an individual volunteer.

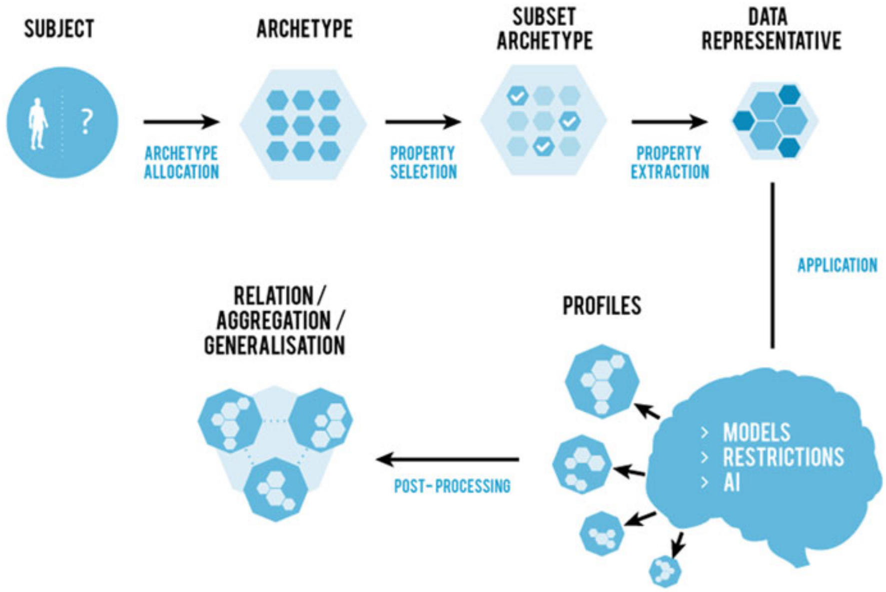


**Fig. 2** Sub-processes of profiling

# 4 Profiling

The term profiling has been frequently used over the last years in different research areas. Within the field of information and computer science it is mainly used in conjunction with the terms: program behavior [9, 10], (web) user [11, 12], network [13], or social media [14].

## 4.1 General Usage

Generally, profiling is defined as "the act or process of learning information about someone based on what is already known" [15]. This definition is vague concerning the act or process used to obtain information and does neither define the kind of information retrieved nor its origin. Due to this lack of an exact definition, an appropriate assignment of methods, techniques or technologies regarding profiling is not possible without clearly distinguishing between the various implementations and their individual context.

In order to specifically define the process of profiling that will be introduced within this paper, it is necessary to present a definition of what profiling describes within the scope of an intelligent volunteer selection in correspondence to aspects of information and computer science. Furthermore, the requirements and outputs that are to be expected by the application of profiling have to be defined.

The term profiling is hereby not to be confused with a profile. A profile is commonly defined as "a brief written description that provides information about someone or something" whereas the verb to profile is defined as the action "to give a brief description [. . .]" [15]. This definition defines a profile as the result of a process generated to describe someone or something, i. e., an abstract representation of the profiled subject.

## *4.2 Definition*

Profiling describes the process of generating profiles from obtained data, associated to one or multiple subjects. A profile itself is a non-empty, finite, ordered tuple with a positive number of elements. Each of these elements consists of a finite number of values corresponding to its individual domain. The process of profiling is divided in multiple sub-processes, which are illustrated in Fig. 2. The various terms describing these sub-processes and the different artifacts which are their results, are shortly described as follows:

1. *Subject*: A subject describes "what" is actually being profiled. Within the VNS, the subject will be a registered user (a human being) but in general, anything can be profiled; e. g., a life-form, medical symptoms or an abstract stream of data. This definition stays in correspondence to the term subject as referred to in [16].
2. *Archetype Allocation*: Due to the generic background of the profiled subjects, the system needs an approximate "idea" of what kind of subject it will deal with. The archetype allocation describes the process of mapping a subject to a specific archetype.
3. *Archetype*: The archetype is an abstract representation of anything that can possibly be profiled. It defines the maximum set of properties that are available on a specific subject. Archetypes can consist of other archetypes as elements; e. g., a human can have a car or children as elements in the archetype, whereas children are themselves represented as humans within this set.
4. *Property Selection*: After a subject has been mapped to an archetype (or a combination of archetypes), it has to be decided which of the available properties are of importance for the profiling process. While it is theoretically useful to support algorithmic selection and re-adjustments in this selection process by implementing a suitable learning strategy, a simplified approach will only process the property selection once, i. e., the properties representing the subject are not modified during the profiling process.
5. *Subset Archetype*: After the relevant properties have been selected from the archetype, the structure of the digital representation of the profiled subject is determined. This artifact is referred to as subset archetype and constitutes the base of the following data representation.
6. *Property Extraction*: The property extraction describes the process of collecting the data (e. g., trough available sensors or automated systems). The selected

properties of the subset archetype will be filled with values. This process will result in the creation of the data representative.

7. *Data Representative*: The data representative conforms to the abstracted, digitalized description of a subject. It consists of the selected properties of its subset archetype and holds the raw data from occurred property extractions. This term is not the same as a data subject introduced in [16] but instead differentiates due to its raw data characteristic.
8. *Application*: This process is defined by the application of different models, processing the data representative. The processing will lead to a profile of the data representative. Possible models are introduced in the upcoming section.
9. *Profile*: A profile is a generalized representation of the data representative. The degree and direction of the generalization is defined by the context of the profiling process, i. e. the applied models.
10. *Post-Processing*: This step describes the generic approach of applying various methods to the existing profiles. Examples are clustering, association analyzes, or the identification of relations between profiles.
11. *Relation/Aggregation/Generalisation*: This artifact describes the result of the post-processing. Examples for this category are sets of profiles which are aggregated by associations or relations between them, or group profiles representing identified group properties.

## 4.3 Application Models

In the context of behavioral predication, application models are generally based on theoretical rational behavior [17], bounded rationality (i. e., psychological models) [18], or on models that are based on observations which are characterized by methods of machine learning algorithms [19]. Beside the sole implementation of a single approach, a combinatorial aggregation of different types of models is possible. Recent research states that especially the use of hybrid models which are based on machine learning, but add features from psychological models, performed significantly better in various domains [20]. An alternative process is the sequential application of different models to a single data representative in order to retrieve specific properties of that profile.

## 4.4 Prescient Profiling

With the data representative uniting the digitalized properties of a subject that were collected over time, a base for further processing is available. Applying different models (as discussed above) will result in individual profiles that enable various operations; e. g., clustering and the evaluation regarding specific criteria. This process conforms to the definition of profiling as given in Sect. 4, while prescient profiling

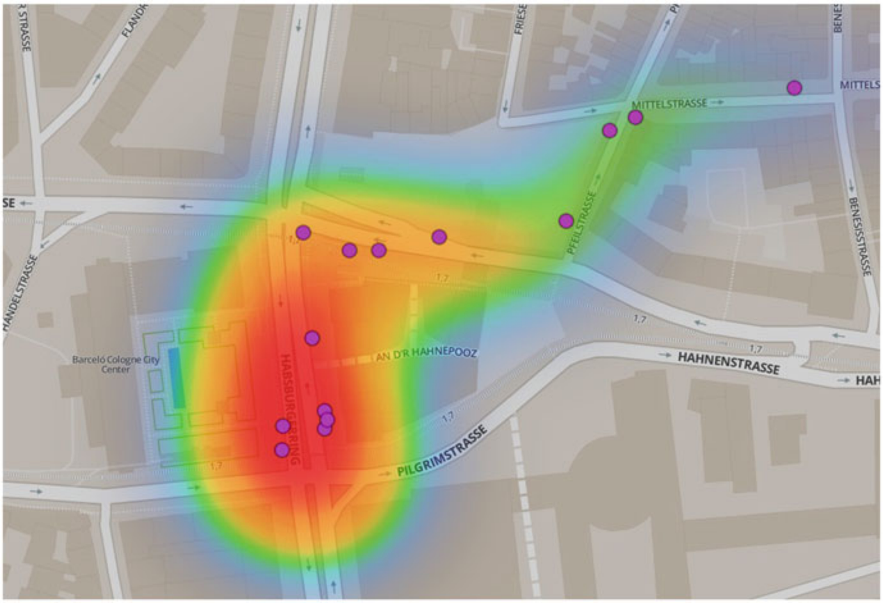


**Fig. 3** Location heat map

may be considered “the next step” on top of this basic definition, using the profile(s) to generate new insights and therefore enable enhanced capabilities.

Implying a learning system approach, thus, a system that uses methods of AI to learn from past observations and thereby identifies trends and patterns, will not be limited to analyzing the historical values but instead will have the ability to make predictions. This states an enhanced definition of profiling. The term “Prescient Profiling” therefor refers to this special type of profiling, aiming to make reliable predictions on both, the value of individual properties and on a profile itself.

## *4.5 Profiling within the VNS*

In the context of a VNS, the subject of profiling will be the volunteer (i. e., the registered user). The corresponding archetype is human with the following, exemplary properties to select from: gender, height, weight, age, location, number of children, type of car. Within the property selection, only the location is selected as property that is filled with data during the property extraction process. This extraction will occur automatically, i. e., the mobile phone will continuously push updated information on the volunteer’s location to the VNS server. All incoming location updates are stored in the data representative of this volunteer and applying specific models will generate different types of profiles. One suitable approach is the generation of a so called heat map [21] as part of the resulting profile. This location heat map, as illustrated in Fig. 3, describes the current whereabouts of the volunteer to be profiled as probabilities, rather than a single valid location; the calculation is based on the available location data from within the data representative (i. e., the purple dots).

By generating profiles of different volunteers and applying post-processing methods, e. g., clustering or pattern recognition, aggregated profiles are being created, representing the relation between different volunteers and their corresponding heat maps. In addition, trends and progresses in the development of individual heat maps can be analyzed in order to create group profiles or enable various predications.

## 5 Conclusion and Outlook

Whereas a basic VNS implementation is able to notify volunteers in the closer vicinity by using simple selection algorithms, various scenarios have been discussed in which an efficient volunteer selection will require the consideration of additional factors. The concept of profiling has been introduced as a suitable solution within this context, aiming to generate profiles of individual volunteers. This is achieved by creating a data representation of the profiled subject, based on specific parameters that are selected from an archetype definition within the property selection and filled with data during the property extraction process. The application of different types of models, integrating various concepts of pattern recognition and machine learning in order to identify behavioral patterns and coherences between volunteers and individual properties, describes an enhanced process of profiling that has been introduced as "Prescient Profiling", utilizing the various profiles to enable predictions on individual subjects or groups.

The research focus of the near future will be the actual implementation of the machine learning approach and the development of corresponding models. The explicit application of Prescient Profiling within the context of the VNS needs to be analyzed, developed and evaluated. With an integration of the VNS system into the emergency workflow of regional EMS partners planned for the beginning of 2014, promising possibilities for an efficient data assessment are being created; enabling benchmarks and comparisons of various selection models in different emergency scenarios and thereby producing academic results on the efficiency of an AI approach for volunteer selection in medical emergencies.

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# Selfoptimized Assembly Planning for a ROS Based Robot Cell

**Daniel Ewert, Daniel Schilberg and Sabina Jeschke**

**Abstract** In this paper, we present a hybrid approach to automatic assembly planning, where all computational intensive tasks are executed once prior to the actual assembly by an Offline Planner component. The result serves as basis of decision-making for the Online Planner component, which adapts planning to the actual situation and unforeseen events. Due to the separation into offline and online planner, this approach allows for detailed planning as well as fast computation during the assembly, therefore enabling appropriate assembly duration even in nondeterministic environments. We present simulation results of the planner and detail the resulting planner's behavior.

**Keywords** Assembly Planning · Cognitive Production Systems · ROS

## 1 Introduction

### *1.1 Motivation*

The industry of high-wage countries is confronted with the shifting of production to low-wage countries. To slow down this development, and to answer the trend towards shortening product life-cycles and changing customer demands regarding individualized and variant-rich products, new concepts for the production in high-wage countries have to be created. This challenge is addressed by the Cluster of Excellence "Integrative production technology for high-wage countries" at the RWTH Aachen University. It researches on sustainable technologies and strategies on the basis of the so-called polylemma of production [1]. This polylemma is spread between two dichotomies: First between scale (mass production with limited product range) and scope (small series production of a large variety of products), and second between value and planning orientation. The ICD) "Self-optimizing Production

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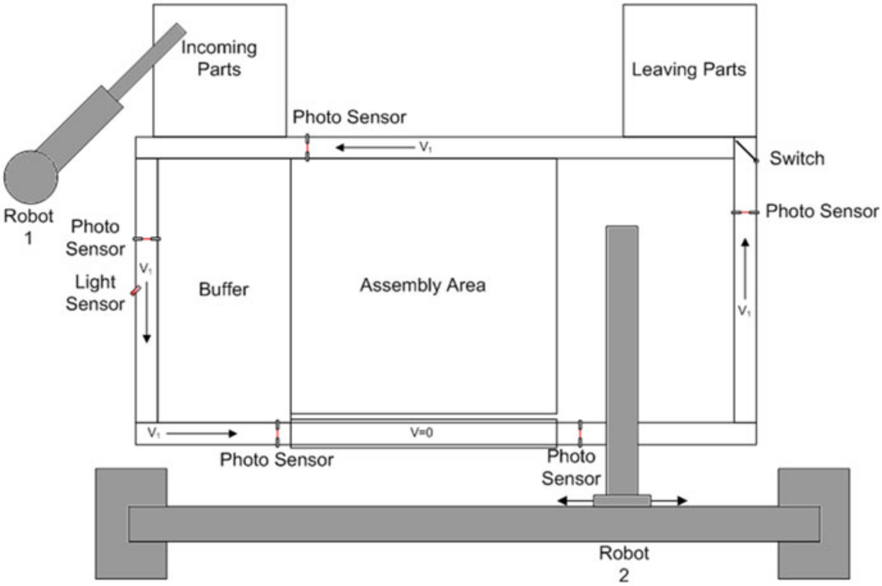


**Fig. 1** Schematic of the robot cell

Systems" focusses on the reduction of the latter dichotomy. It's approach for the reduction of this polylemma is to automate the planning processes that precede the actual production. This results in a reduction of planning costs and ramp-up time and secondly it allows to switch between the production of different products or variants of a product, hence enabling more adaptive production strategies compared to current production. Automatic replanning also allows to react to unforeseen changes within the production system, e. g. malfunction of machines, lack of materials or similar, and to adapt the production in time. In this paper we present the planning components of a cognitive control unit (CCU) which is capable to autonomously plan and execute a product assembly by relying entirely on a CAD description of the desired product.

## *1.2 Use Case Description*

The CCU is developed along a use case scenario for an assembly task in a nondeterministic production environment [2]. This scenario is based on the robot cell depicted in Fig. 1.

Of the two robots of the robot cell, only Robot2 is controlled by the CCU. Robot1 independently delivers parts in unpredictable sequence to the circulating conveyor belt. The parts are then transported into the grasp range of Robot2 who then can decide to pick them up, to immediately install them or to park them in the buffer area.

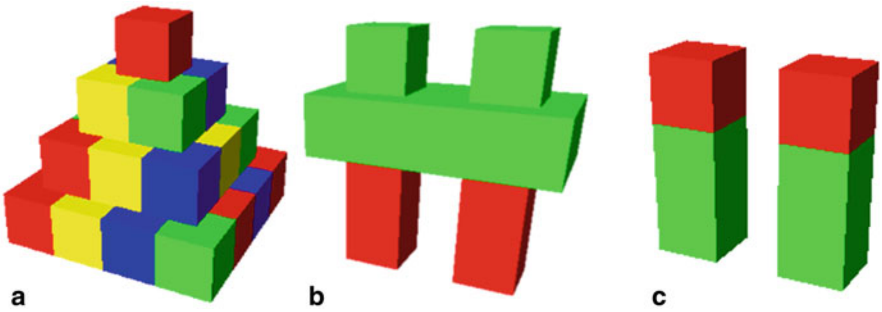


**Fig. 2** Toy model products for planner evaluation

The scenario also incorporates human-machine cooperation. In case of failure, or if the robot cannot execute a certain assembly action, the CCU is able to ask a human operator for assistance. To improve the cooperation between the operator and the machine, the operator must be able to understand the behavior and the intentions of the robot [3]. Therefore, machine transparency is a further major aspect in our concept.

The only sources of information to guide the decision making of the CCU are a CAD description of the desired product, the number and types of single parts currently in the buffer and on the conveyor belt and the current state of the assembly within the Assembly Area. The planner is evaluated with the figures described in Fig. 2. The pyramid construct a (Fig. 2a) serves here as a benchmark for the computational complexity of our planning approach and has been used in different sizes (base areas of $2 \times 2$, $3 \times 3$, and $4 \times 4$ blocks). Construct b and c (Fig. 2b, c) are used to demonstrate the planner's behavior.

## 2 Related Work

In the field of artificial intelligence planning is of great interest. There exist many different approaches to planning suitable for different applications. Hoffmann developed the FF planner, which is suitable to derive action sequences for given problems in deterministic domains [4]. Other planners are capable to deal with uncertainty [5] [6]. However, all these planners rely on a symbolic representation based on logic. 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 time.

Other planners have been designed especially for assembly planning and work directly on geometric data to derive action sequences. A widely used approach is the Archimedes system by Kaufman et al. [7] that uses And/Or-Graphs and an "Assembly by Disassembly" strategy to find optimal plans. U. Thomas [8] follows this strategy, too, but where the Archimedes system relies on additional operator-provided data to find feasible subassemblies, Thomas uses only the geometric information about the final product as input. However, both approaches are not capable of dealing with uncertainty.

Other products for assembly planning focus on assisting product engineers set up assembly processes. One example is the tool Tecnomatix from Siemens [9], which assists in simulating assembly steps, validates the feasibility of assembly actions etc. All of the mentioned works do not cover online adaption of assembly plans to react on changes in the environment. One exception is the system realized by Zaeh et al. [10], which is used to guide workers through an assembly process. Dependent on the actions executed by the worker, the system adapts its internal planning an suggests new actions to be carried out by the worker. The CCU uses the same technique for plan adaption.

## 3 Autonomous Assembly Planning

### *3.1 Hybrid Assembly Planning*

The overall task of the CCU is to realize the autonomous assembly in a nondeterministic environment: Parts are delivered to the robot cell in random sequence and the successful outcome of an invoked assembly action cannot be guaranteed. While assembly planning is already hard even for deterministic environments where all parts for the assembly are available or arrive in a given sequence [8], the situation becomes worse for this unpredictable situation. One approach to solve the nondeterministic planning problem would be to plan ahead for all situations: Prior to the assembly all plans for all possible arrival sequences are computed. However, this strategy soon becomes unfeasible: A product consisting of n parts allows for n! different arrival sequences, so a product consisting of ten parts would already result in the need to compute more than 3.6 MIO plans. Another approach would be to replan during the assembly every time an unexpected change occurs in the environment. This strategy, however, leads to unacceptable delays within the production process.

Therefore, our approach follows a hybrid strategy. All computational intensive tasks are executed once before the actual assembly. This is done by an Offline Planner component. The results of this step serve as basis of decision-making for the Online Planner component, which adapts planning to the actual situation and unforeseen events. Due to this separation, our approach (see Fig. 3) allows for detailed planning as well as fast computation during the assembly, therefore enabling appropriate assembly duration even in nondeterministic environments. The Offline Planner contains a CAD Parser which derives the geometric properties. The currently supported format is STEP [11]. This data is then processed by the graph generator. The details of this process are explained in Sect. 3.2. The Online Planner consists of the components Graph Analyzer, Parallelizer and Cognitive Control, which are detailed in Sect. 3.3.

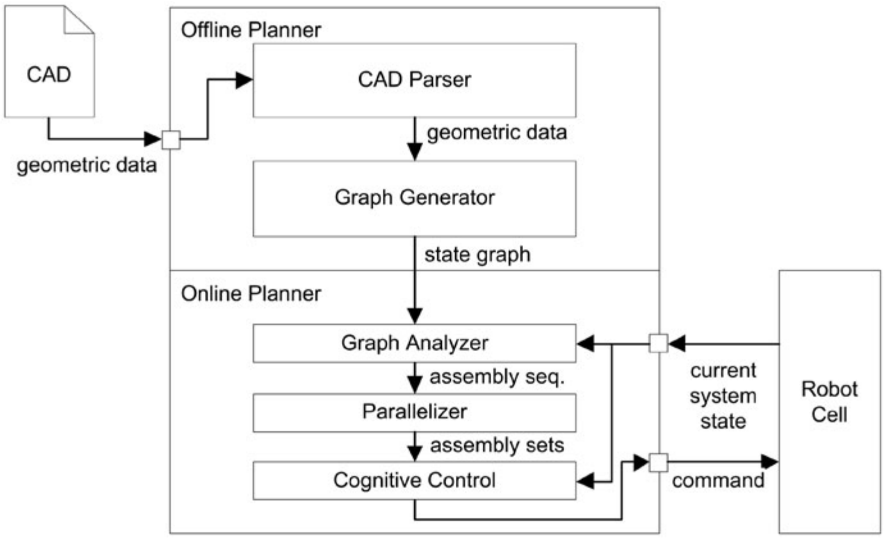


**Fig. 3** System overview of the hybrid approach

### *3.2 Offline: Graph Generation*

The Offline Planner receives a CAD description of the desired final product. From this input it derives the relations between the single parts of the product via geometrical analysis as described in 0. The results are stored in a connection graph. Assembly sequences are now derived using an assembly-by-disassembly strategy: Based on the connection graph, all possible separations of the product into two parts are computed. The feasibility of those separations is then verified using collision detection techniques. Unfeasible separations are discarded. The remaining separations can then be evaluated regarding certain criteria as stability, accordance to assembly strategies of human operators or similar. The result of this evaluation is stored as a score for each separation. This separation is recursively continued until only single parts remain. The separation steps are stored in an and/or graph [12], which is then converted into a state graph as displayed in Fig. 4 using the method described in Ewert D., D. Schilberg, and S. Jeschke [13]. Here nodes represent subassemblies of the assembly. Edges connecting two such nodes represent the corresponding assembly action which transforms one state into the other. Each action has associated costs, which depend on the type of action, duration, etc. Also, each edge optionally stores information about single additional parts that are needed to transform the outgoing state into the incoming state.

The graph generation process has huge computational requirements for time as well for space. Table 1 shows the properties of resulting state graphs for different products. The results show the extreme growth of the graph regarding the number of parts necessary for the given product. However, as can be seen when comparing

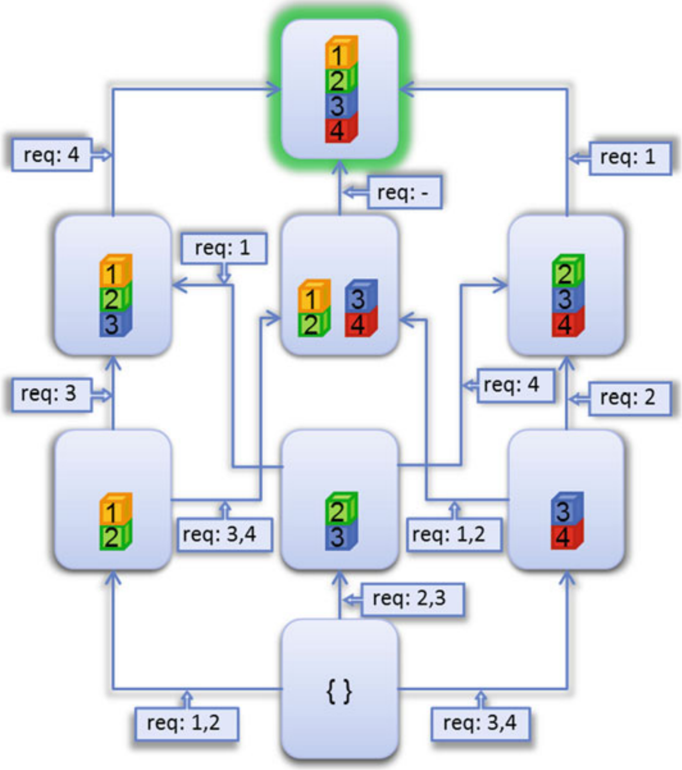


**Fig. 4** State graph representation of the assembly of a four blocks tower

**Table 1** State graph properties for different products

| Product | #Parts | #Nodes of graph | #Edges of graph |
|---|---|---|---|
| Construct a (size 2 × 2) | 5 | 17 | 33 |
| Construct c | 6 | 16 | 24 |
| Construct b | 14 | 361 | 1330 |
| Construct a (size 3 × 3) | 14 | 690 | 2921 |
| Construct a (size 4 × 4) | 30 | 141,120 | 1,038,301 |

the state graphs of both constructs with 14 parts, the shape of a product affects the graph, too: The more possible independent parts are from each other, the more different assembly sequences are feasible. Therefore the graph of the construct a (Fig. 2a) with 14 parts has almost twice the size of the state graph resulting from construct b (Fig. 2b).

### 3.3 Online: Graph Analysis

The state graph generated by the Offline Planner is then used by the Online Planner to derive decisions which assembly actions are to be executed given the current situation of an assembly. The Online Planner therefore executes the following process iteratively until the desired product has been assembled: The Graph Analyzer perceives the current situation of the assembly and identifies the corresponding node of the state graph. In earlier publications [13] we suggested an update phase as next step. In this phase all costs of the graphs edges reachable from that node were updated due to the realizability of the respective action. The realizability depends on the availability of the parts to be mounted. Unrealizable actions receive penalty costs which vary depending on how close in the future they would have to be executed. This cost assignment makes the planning algorithm avoid currently unrealizable assemblies. Additionally, due to the weaker penalties for more distanced edges, the algorithm prefers assembly sequences that rely on unavailable parts in the distant future to assemblies that immediately need those parts. Preferring the latter assembly results in reduced waiting periods during the assembly since missing parts have more time to be delivered until they are ultimately needed. Using the A* algorithm [14] the Online Planner now derives the cheapest path connecting the node matching the actual state with a goal node, which presents one variant of the finished product. This path represents the at that time optimal assembly plan for the desired product. The Parellelizer component now identifies in parallel or arbitrary sequence executable plan steps and hands the result to the Cognitive Control for execution. Here the decision which action is actually to be executed is made. The process of parallelization is detailed in [13].

However, updating all edge cost reachable from the node representing the current state is a computational intensive task. To overcome this problem, the edge cost update can be combined with the A* algorithm, so that only edges which are traversed by A* are updated. This extremely reduces the computational time, since only a fraction of the graphs node is examined. So even for large graphs, the Online Planner is able to derive a decision in well under 100 ms in worst case. Figure 5 shows the nodes reachable and examined by the Online Planner during the assembly of a $4 \times 4$ construct. Plateaus in the graph depict waiting phases where the assembly cannot continue because crucial parts are not delivered.

### 3.4 Planner Behaviour

Figure 6 shows the course of the assembly for the construct c (Fig. 2c). Newly arrived parts are shown in the third column. They can either be used for direct assembly (first column) or otherwise are stored in a buffer shown in column 2. The right column depicts the plan that is calculated based on the parts located. Here the number of a given block denotes the position where that block is to be placed. In step 0, no parts have been delivered. The planner therefore has no additional information and

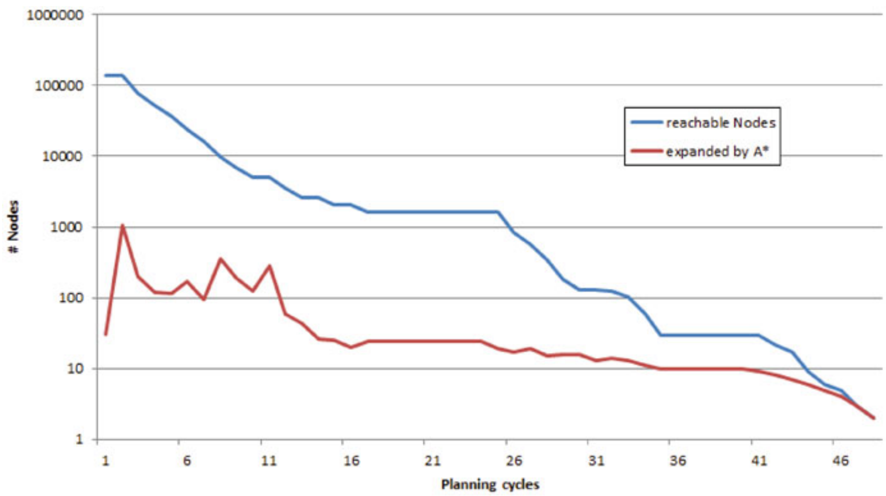


**Fig. 5** Number of nodes reachable from the node representing the given situation and number of nodes that are examined by the A*-algorithm. Number of nodes is shown using a logarithmic scale

produces an arbitrary but feasible plan. In step 1 a new green block is delivered, which matches the first plan step. The related assembly action is therefore executed and the new block is directly put to the desired position. In step 2 a new red block is delivered. Given the current state of the assembly and the new red cube, the planner calculates an improved plan which allows to assemble this red block earlier than originally planned: Now it is more feasible to first mount two green blocks on top of each other (positions 1 and 3), because then the red block can be assembled, too (position 5). This plan step is executed in step 3 when a second green block becomes available. Now, in step 4, it is possible to mount a red block. From that step on only one feasible assembly sequence is possible, which is then executed.

The described behaviour results in more rapid assemblies compared to simpler planning approaches: A purely reactive planner which would follow a bottom up strategy, would have placed the first two green blocks next to each other (positions 1 and 2). Thus, in step 5 no assembly action would have been possible and the assembly would have to stop until a further green cube would be delivered.

## 4 Summary

In this paper we presented our hybrid approach for an assembly planner for nondeterministic domains. We described the workflow of the offline planner, which analyses CAD data describing the desired product. The outcome of the offline planner is a state graph which holds alle possible (and feasible) assembly sequences. This graph

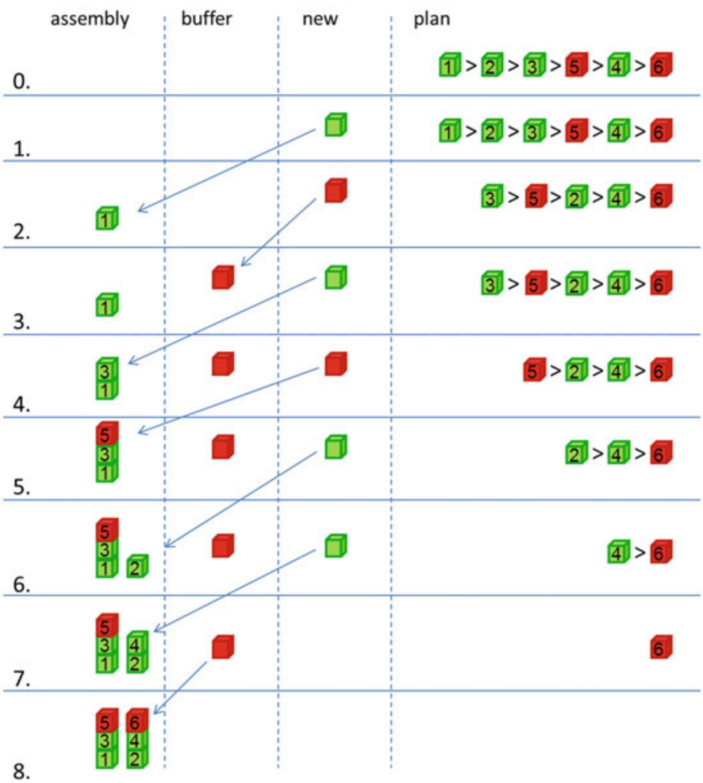


**Fig. 6** Exemplary assembly flow for construct c

is generated by following an assembly by disassembly strategy: Recursively all possible separations of the final product are computed until only single parts remain. During the actual assembly, this state graph is updated to mirror the current situation of the assembly, specially the availability of newly delivered parts. Using the A* algorithm, the at that time optimal assembly sequence is derived and handed over to the cognitive control unit, which then decides which assembly step gets to be executed. This step is then executed and the outcome of that step is reported back to the planning system. This process is iterated until the product is completed.

## 5 Outlook

Future work must optimize the described Planners. Using techniques of parallel programming and by incorporating specialized databases which can cope efficiently with large graphs, the planning duration can be improved. Subsequently, the planner will be extended to be able to deal with industrial applications as well as plan and control the production process of a complete production network.

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# CloudLogistic – Geschäftsmodellentwicklung für eine Frachtenkooperation kleiner und mittlerer Straßengüterverkehrsunternehmen im Teilladungssegment

**Phil Friedrichsmeier, Nadine Voßen, Christian Tummel, Eckart Hauck und Sabina Jeschke**

**Zusammenfassung** Dieser Beitrag adressiert einen ersten Entwurf eines Geschäftsmodells für eine Frachtenkooperation von kleinen und mittleren Speditionsunternehmen des Straßengüterverkehrs im Bereich von Teilladungstransporten. Zunächst erfolgt eine kurze Einführung, in der die Relevanz von Frachtenkooperationsbildungen kleiner und mittlerer Speditionsunternehmen aufgezeigt wird. Im Gegensatz zum Stückgut- und Komplettladungsbereich existiert für den Transport von Teilladungen allerdings bis dato noch kein optimiertes Logistikkonzept für klein- und mittelständische Transportnetzwerke im Straßengüterverkehr. Das CloudLogistic-Szenario wird als ein geeigneter Ansatz vorgestellt, um dieser Problemstellung zu begegnen. Den Kern dieses Beitrags bildet der Geschäftsmodellentwurf für diesen Frachtenkooperationstyp mittels der Business-Model-Canvas-Methodik von Osterwalder/Pigneur, da dieser Ansatz gerade für die Eingangsphase im Rahmen von Geschäftsmodellkonzeptionen bzw. bei Geschäftsmodellinnovationen geeignet ist. Der Beitrag empfiehlt, den Entwurf des Geschäftsmodells um eine geeignete Business-Architektur, die die relevanten Geschäftsprozesse im Hinblick auf die sich anschließende Konzipierung der IT-Architektur für die optimierte Zentraldisposition beinhaltet, zu erweitern.

**Schlüsselwörter** CloudLogistic · Geschäftsmodell · Geschäftsmodellentwicklung · Frachtenkooperation · Straßengüterverkehr/Straßengüterfernverkehr · Teilladungssegment

## 1 Einführung

In seiner jüngsten Studie zur Verkehrsverflechtung in Deutschland prognostiziert das Bundesministerium für Verkehr, Bau und Stadtentwicklung (BMVBS) ein erhebliches Wachstum des Verkehrsaufkommens im Straßengüterverkehr bis zum Jahr 2025.

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Zu dieser Entwicklung trägt besonders der Straßengüterfernverkehr mit einem Wachstum des Transportaufkommens um 55 % und der Verkehrsleistungen um 84 % bei [1, S. 200 f.]. Trotz dieser Entwicklung werden in Deutschland fast 20 % der gefahrenen Kilometer im gewerblichen Güterverkehr gänzlich ohne Beladung zurückgelegt [2, S. 14 f.]. Aus ökologischen und ökonomischen Gründen ist es notwendig, einerseits eine bestmögliche Nutzung des vorhandenen Laderaums zu erreichen, um die CO2-Belastung zu verringern, und andererseits zur allgemeinen Steigerung der Effizienz im Straßengüterverkehr.

Zur Stärkung der eigenen Marktposition haben zahlreiche Unternehmen in der Logistikbranche begonnen, mit anderen Unternehmen zu kooperieren. Insbesondere kleine und mittlere Speditionsunternehmen sind heutzutage immer stärker darauf angewiesen, Synergieeffekte speditionsübergreifender Kooperationen zu nutzen und mit konkurrierenden Unternehmen zusammenzuarbeiten. Es bilden sich horizontale Kooperationen auf dem Markt, die es den Speditionen ermöglichen, den eigenen Servicegrad zu verbessern und die eigene Marktposition u. a. durch verbesserte Flächendeckung auszubauen bzw. zu stärken [3, S. 23]. Bisher wird dabei vermehrt auf das Angebot von Frachtenbörsen oder Logistiknetzwerken zurückgegriffen.

Im Stückgut- und Komplettladungsbereich konnten Frachtenbörsen oder Stückgutkooperationen bereits erheblich zur Steigerung der Wettbewerbsfähigkeit kleiner und mittlerer Speditionen beitragen. Für den Transport von Teilladungen existiert allerdings bis heute noch kein optimiertes Logistikkonzept für mittelständische Transportnetzwerke im Straßengüterverkehr. Als Teilladung werden Sendungen bezeichnet, die einerseits den Laderaum des Transportmittels nicht vollständig auslasten, andererseits aufgrund ihrer Größe oder entsprechender Vorgaben (u. a. Gefahrengut, Umschlagverbot durch Kunden etc.) nicht umgeschlagen werden [4, S. 1057 f.]. Der wirtschaftliche Druck, u. a. durch die Einführung der Lkw-Maut führt dazu, dass besonders im Teilladungssegment die ökonomische Belastung wächst. Kleine und mittelständische Speditionen sind durch diese Entwicklung zunehmend auf speditionsübergreifende Lösungen angewiesen, um dieser Belastung entgegenzuwirken. Um ein Kooperationsnetzwerk im Teilladungssegment langfristig erfolgreich zu etablieren, bedarf es der Entwicklung eines geeigneten Geschäftsmodells zur Integration der Anforderungen, die aus den Bedürfnissen teilnehmender Speditionsunternehmen und systemrelevanter Umweltfaktoren resultieren und abgeleitet werden.

Nach der Skizzierung der grundlegenden Problemstellung erfolgt im Abschn. 2 die Vorstellung des Lösungsansatzes, der im Projekt CloudLogistic angewendet wird, und darauf aufbauend im Abschn. 3 ein Entwurf eines Geschäftsmodells für eine Frachtenkooperation kleiner und mittlerer Speditionsunternehmen im Teilladungssegment. Abschließend wird im Abschn. 4 ein Fazit der vorgestellten Überlegungen gezogen sowie ein Ausblick gegeben.

## 2 Das CloudLogistic-Szenario – Lösungsansatz für eine linienbasierte Teilladungskooperation

Die Grundidee des CloudLogistic-Szenarios ist es, Teilladungen mehrerer kooperierender Speditionen über ein zentralgesteuertes Kooperationsmodell zu bündeln, und diese dann umschlagsfrei – durch die Zusammenfassung mehrerer Teilladungen – zu disponieren und Synergieeffekte zu nutzen.

Dazu wird ein speditionsübergreifender, dynamischer LKW-Linienbetrieb zwischen einzelnen Regionen in Deutschland aufgebaut. Teilladungsaufträge werden zentral über das Kooperationsnetzwerk gebündelt. Für eine kombinierte Disposition der Sendungen werden Fracht-Linien eingerichtet, d. h. Relationen zwischen einem Quell- und einem Zielgebiet, die von Transportmitteln regelmäßig im Direktverkehr bedient werden (siehe Abb. 1). Die Transportmittel werden von den Kooperationspartnern zur Verfügung gestellt [5, S. 3].

Drei wesentliche Kernaspekte dieses Logistikkonzepts stellen

- der umschlagsfreie Direktverkehr,
- das optionales Pick-Up entlang der Relationen und
- die Verwendung von Geo-Koordinaten statt Postleitzahlen-Grenzen

dar.

Eine zentralgesteuerte und optimierte Disposition von Teilladungen ohne Hub-Verkehr ermöglicht die Realisierung eines umschlagsfreien Direktverkehrs (siehe Abb. 2, links). Damit werden die anfallenden Kosten durch den Umweg über ein Hub eingespart und Kundenvorgaben, wie z. B. ein Umschlagsverbot der Ladung, berücksichtigt.

Spontan auftretende Teilfrachtaufträge, die in die Kooperationsplattform von Kooperationspartnern eingestellt werden, können mittels des optionalen Pick-Up,

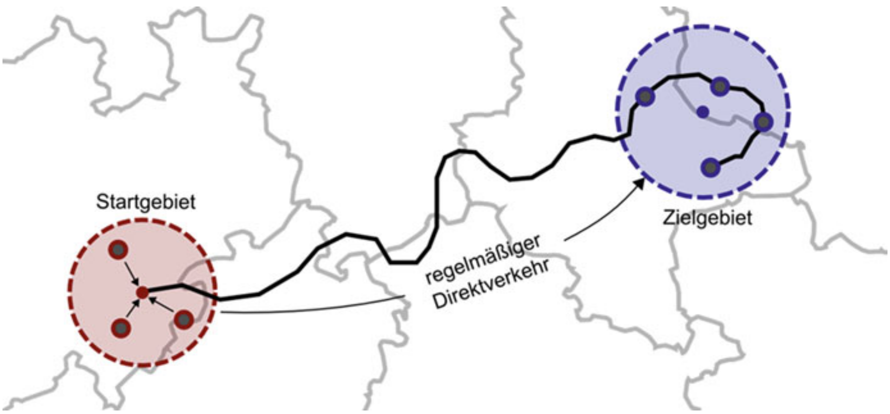


**Abb. 1** Beispielhafte Darstellung einer Fracht-Linie als Relation zwischen einem Start- und Zielgebiet [5]

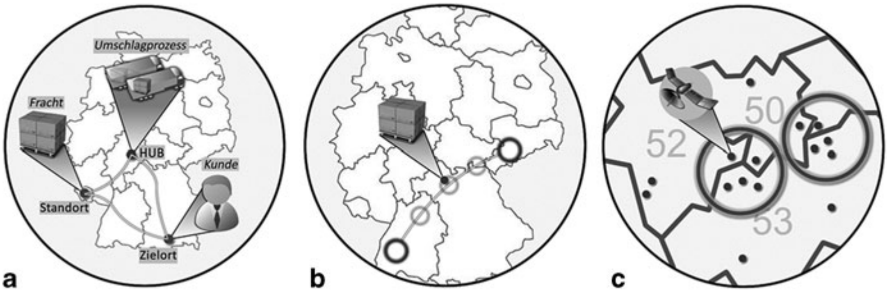


**Abb. 2** Direktverkehr ohne Hub-Umschlag (*links*), Optionales Pick-Up während der Fahrt (*mittig*) sowie Disposition über Geokoordinaten (*rechts*)

bereits fahrenden Lkw auf diesen Linien zugeordnet werden, sofern diese die nähere Umgebung des Frachtstandortes in Kürze kreuzen, über den Frachtraum für eine zusätzliche Ladung verfügen und ausreichende zeitliche Kapazitäten bieten (siehe Abb. 2, mittig). Darüber hinaus können kostenintensive Leerfahrten insbesondere auf der Rückfahrt durch die Möglichkeit des optionalen Pick-Up vermieden werden.

Durch den Einsatz positionsgenauer Geokoordinaten können die Frachtstandorte und die aktuelle Positionen der Lkw jederzeit bestimmt werden. Die Disposition selbst erfolgt darauf aufbauend ebenfalls unabhängig von Postleitzahlengrenzen über die geographische Position von Quell- und Zielort (siehe Abb. 2, rechts).

## 3 Geschäftsmodellentwurf für diesen Kooperationstypus

Der Begriff Geschäftsmodell hat sich seit den 90er Jahren für die grundlegende Beschreibung der Funktionsweise von Unternehmensformen durchgesetzt [6, S. 1 f.]. Geschäftsmodelle sind für eine übersichtliche Darstellung von Organisationen, deren Einheiten sowie deren Geschäftstätigkeiten nutzbar; sie fungieren als Bindeglied zwischen einer Geschäftsidee und einem aufzustellenden Business-Plan [7, S. 7 f.].

Der Begriff des Geschäftsmodells wird bis dato in der Literatur uneinheitlich definiert[1] [8, S. 65 ff.]. Bei vielen definitorischen Ansätzen werden konkrete Elemente eines Geschäftsmodells aufgegriffen und eine dahinterliegende Beziehungsstruktur dieser Elemente untereinander beschrieben. Die andere große Gruppe von Definitionen stammt aus einem konkreten Anwendungsszenario, bei denen kein näher definiertes Komponenten- und Beziehungsgerüst im Hinblick auf das Geschäftsmodell besteht [9, S. 16 f.].

Dennoch umfassen die meisten Definitionsansätze die Betrachtung eines Unternehmens mit Akteuren und Rollen, von Finanz- und Produkt-Flüssen innerhalb des

[1] Eine Übersicht kann Wirtz [8] entnommen werden.

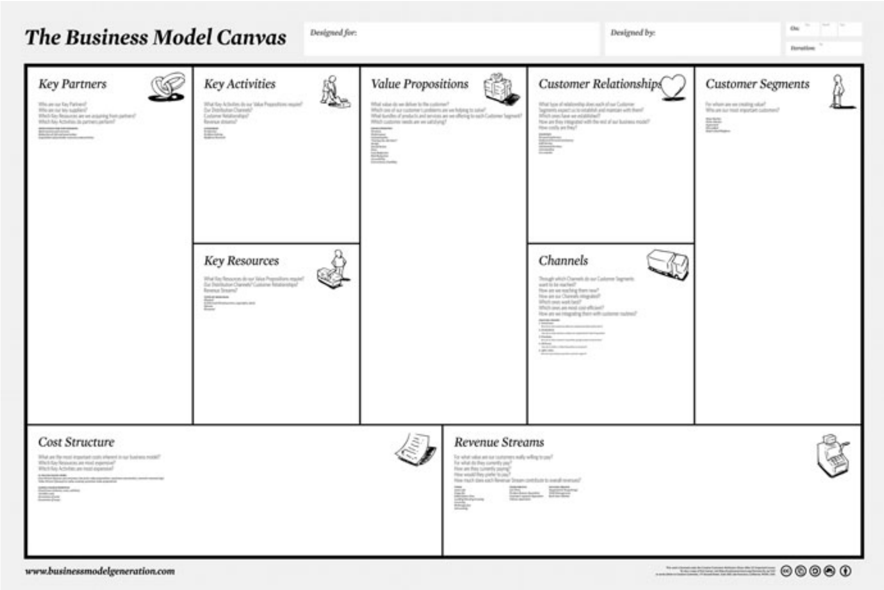


**Abb. 3** Business Model Canvas. (Quelle: http://www.businessmodelgeneration.com/canvas)

Unternehmens, der Wertschöpfung und des Nutzenversprechens des Unternehmens sowie externer Einflussfaktoren auf das Unternehmen [9, S. 20 f.].

Unter einem Geschäftsmodell wird an dieser Stelle ein Abbild der Geschäftstätigkeit eines Unternehmens unter Berücksichtigung der angebotenen Produkte und Dienstleistungen, der Kundensegmente und deren Einbeziehung in den Wertschöpfungsprozess, der Einnahmequellen und Kostenstruktur, der Kernaktivitäten und -ressourcen sowie Einbindung der (externen) Partner verstanden. Ziel ist dabei, die Geschäftslogik eines Unternehmens bzw. einer Geschäftsidee vereinfacht darzustellen.

Für den Entwurf eines Geschäftsmodells für eine Frachtenkooperation im Teilladungssegment wird in den weiteren Ausführungen auf die von Osterwalder und Pigneur entwickelte Methodik der „Business Model Canvas" [10, S. 14 ff.] zurückgegriffen (siehe Abb. 3). Diese stellt eine der am häufigsten angewendeten Methoden in der Praxis dar und wird darüber hinaus oftmals als Referenzmodell im Rahmen der Geschäftsmodellforschung und -entwicklung genutzt [11, S. 27].

Der wesentliche Vorteil des Ansatzes liegt in der generischen Verwendungsmöglichkeit für unterschiedliche Modellierungsszenarien. Der Ansatz ist sowohl für die Entwicklungsphase eines Geschäftsmodells als auch für Geschäftsmodellinnovationen geeignet [11, S. 189 f.]. Ein Problem der Methodik besteht darin, dass es in der aktuellen Form für die operative Einbindung in Geschäftsprozesse nicht geeignet ist [11, S. 190]. Daher muss die „Business Model Canvas" um eine flexible Business-Architektur erweitert bzw. ergänzt werden, damit die Geschäftsprozesse der Frachtenkooperation mit den relevanten Schnittstellen und

Wertflüssen, auf denen die Implementierung der IT-gestützten Zentraldisposition basiert, definiert und modelliert werden können.

Da eine ständige (Weiter-)Entwicklung des Geschäftsmodells erfolgen muss (beispielweise auf Basis sich verändernden Anforderungen oder der Erweiterung des Produktportfolios), stellt die „Business Model Canvas" dennoch eine sehr geeignete Methodik dar, weil sie für ein iteratives Vorgehen ausgelegt ist. Überarbeitungen und Ergänzungen des Geschäftsmodells – resultierend aus den wechselseitigen Einflüssen der verschiedenen Segmente untereinander – sind jederzeit möglich.

Zur Ermittlung der Anforderungen an ein Geschäftsmodell einer Frachtenkooperation im Teilladungssegment sind im Projekt CloudLogistic mehrere Expertenarbeitskreise mit Mitgliedern der Geschäftsleitungen kleiner und mittlerer Speditionen durchgeführt worden. Bei diesen Arbeitskreisen, die in verschiedenen wirtschaftlichen Großräumen in Deutschland durchgeführt wurden, nahmen pro Termin ungefähr 40 Personen aus dem obigen Personenkreis zuzüglich weiterer Fachexperten teil. Diese hatten die Möglichkeit, Ihre Anforderungen an das Geschäftsmodell in Form von „GO'S", „NO GO'S" sowie weiterführender „Ideen" zu formulieren.

Anschließend wurden die erhobenen Anforderungen spezifiziert und den einzelnen Segmenten der „Business Model Canvas" zugeordnet. Diese neun Segmente, die die Kernbereiche Kunden(-struktur) [*Customer Segments, Channels* sowie *Customer Relationships*], Produkt- und Dienstleistungsangebot [*Value Propositions*], Infrastruktur [*Key Resources, Key Activities* sowie *Key Partnerships*] sowie wirtschaftliche Leistungsfähigkeit [*Cost Structure und Revenue Streams*] umfassen, werden anschließend vorgestellt (siehe auch Abb. 3).

*Customer Segments* Das Kundensegment besteht aus kleinen und mittleren Speditionsunternehmen, die Güter im Teilladungssegment transportieren. Dabei wird im Hinblick auf das Geschäftsmodell zwischen teilnehmenden Spediteuren und potentiellen Mitgliedern der Kooperation unterschieden.

*Value Propositions* Die Wertschöpfungsangebote für teilnehmende Spediteure bestehen in der Maklerfunktion von optimierten, zentraldisponierten Transporten von Teilladungen mittels eines dynamischen, umschlagfreien Direktverkehrs über Frachtlinien. Die Disposition erfolgt dabei über Geokoordinaten unabhängig von Postleitzahlengrenzen. Es wird ein optionales Pick-Up von Ladungen während der Fahrt ermöglicht.

*Channels* Die Kanäle, über welche die Kunden erreicht werden, sind untergliedert in Kommunikations-, Vertriebs- und Verkaufskanäle. Die Kommunikation zum Zwecke der Geschäftsanbahnung (Mitgliedschaft) erfolgt im Wesentlichen über persönliche Vor-Ort-Akquise durch die Kooperation, direkte Post-Anschreiben, per Social Media via Internet sowie über Partnerwerbung durch bestehende Mitglieder. Der Vertriebs- und Verkaufskanal umfasst ein Anmeldeverfahren, das in einem Vertragsschluss mündet; im Anschluss können neue Mitglieder eigene Teilladungsaufträge in die Kooperationsplattform einstellen.

*Customer Relationships* Die Kundenbeziehungen sind durch das Nischensegment Teilladungstransport geprägt. Die Kundengewinnung erfolgt über das Alleinstellungsmerkmal des optimierten Teilladungstransports im dynamischen Direktverkehr. Bestandkundenpflege erfolgt über die Einrichtung von Belohnungs- bzw. Bewertungssystemen (beispielsweise Statusverbesserung von Mitgliedern, Prämien, Bewertung durch die Endkunden, usw.). Als weiteres Element wird ein Eskalations- und Sanktionsmanagement initiiert, um Differenzen unter den Kooperationspartner zu begegnen und die ordnungsgemäße Durchführung der Transporte sicherzustellen. Als Zusatznutzen werden für die Kooperationsmitglieder Schulungskonzepte (beispielsweise zu rechtlichen Fragestellungen, zur Gewinnung und Qualifizierung von Personal, etc.). entwickelt.

*Revenue Streams* Die Einnahmequellen setzen sich hauptsächlich aus den Beiträgen der Mitglieder der Kooperation zusammen. Zunächst werden Eintrittsbeiträge für den Beginn der Mitgliedschaft erhoben, darüber hinaus sind Monats- bzw. Jahresbeiträge zu entrichten. Die Frachtlinien-Konzessionen müssen durch die Partner ebenfalls erworben werden. Die Preisbildung für die Sendungen erfolgt neben der Entfernung zwischen den Mittelpunkten der Quell- und Zielgebiete auf Basis des Kapazitätsvolumens der jeweiligen Linie sowie einem zeitlichen Zonenmodell innerhalb dieser Quell- und Zielgebieten.

*Key Resources* Die Schlüsselressourcen der Kooperation sind Humanressourcen sowie physikalische bzw. materielle Ressourcen. Humanressourcen werden auf Seiten der Mitglieder-Pflege und -Akquisition, der Finanzbuchhaltung, der IT-Systemadministration, der Chefdisposition sowie der Software-Entwicklung und -Distribution benötigt. Es bedarf ggf. eines Business-Architekten für die Analyse und Anpassung von Geschäftsprozessen aufgrund sich verändernder Anforderungen. Auf Seite der physikalischen bzw. materiellen Ressourcen müssen Hard- und Software für die IT-gestützte Zentraldisposition bereitgestellt sowie entsprechende Räumlichkeiten angemietet werden.

*Key Activities* Auf Seiten der Schlüsselaktivitäten muss die Sicherung der Funktionalität der IT-gestützten Zentraldisposition im Vordergrund stehen. Dazu zählt auch die Software-Weiterentwicklung auf Basis sich ändernder Anforderungen sowie die Erstellung von Schulungskonzepten für Kunden zur Software-Einführung und die Schulungsdurchführung. Die Vereinnahmung von Mitgliedsbeiträgen und Konzessionserlösen sowie die Vergütung der Aufträge der Mitglieder bilden einen weiteren Schwerpunkt. Ständiges Controlling und Etablierung von Qualitätsmanagement-Maßnahmen runden das Segment ab.

*Key Partnerships* Die Schlüsselpartner der Kooperation sind deren Mitglieder mit deren Ressourcen (Lkw-Nutzung und Transport). Weitere Partner sind externe Frachtenbörsen, aus denen Sendungen aufgekauft werden, und andere Frachtenkooperationen (beispielweise aus dem Stückgutbereich), mit denen ein Sendungsaustausch betrieben wird. Darüber hinaus wird mit ausgewählten IT-Lieferanten kooperiert, welche die für die Disposition benötigte Soft- und Hardware in ausreichender Menge bei gleichbleibender Qualität liefern.

*Cost Structure* Zur Kostenstruktur kann festgehalten werden, dass die hauptsächlichen Kosten im Bereich der Humanressourcen anfallen. Neben den Personalkosten sind Kosten für Hard- und Software für die IT-gestützte Zentraldisposition sowie Mietzinsen für die Anmietung geeigneter Räumlichkeiten zu berücksichtigen.

Nach der Zuordnung der unter den Spediteuren erhobenen und spezifizierten Anforderungen zu den einzelnen neun Segmenten der „Business Model Canvas“ ist ein erster Entwurf für das Geschäftsmodell einer Frachtenkooperation kleiner und mittlerer Speditionsunternehmen im Teilladungssegment entstanden. Dieser Entwurf erlaubt eine Übersicht über die Funktionsweise der Kooperation mit den Kernbereichen Kunden(-struktur), Produkt- und Dienstleistungsangebot, Infrastruktur sowie wirtschaftliche Leistungsfähigkeit, die einer weiteren Spezifizierung bedürfen. Dieser iterative Entwicklungsprozess erfolgt in enger Abstimmung zwischen dem CloudLogistic-Konsortium sowie weiterer Experten aus der Speditions- und Logistikbranche.

## 4 Fazit und Ausblick

Die Bildung von Frachtenkooperationen ist aus ökonomischer wie auch ökologischer Sicht wichtig, damit kleine und mittlere Speditionsunternehmen des Straßengüterverkehrs im Bereich von Teilladungstransporten gegenüber den Großunternehmen langfristig wettbewerbsfähig bleiben. Mit dem CloudLogistic-Szenario wird ein innovativer Ansatz beschritten, der mittels der zentralgesteuerten Disposition eine Optimierung von Teilladungstransporten verspricht.

Für diesen Typus der Kooperation wurde ein erster Entwurf für ein Geschäftsmodell mittels der „Business Model Canvas“ vorgenommen, da dieser Ansatz gerade für die Eingangsphase im Rahmen von Geschäftsmodellkonzeptionen bzw. bei Geschäftsmodellinnovationen geeignet ist. Dieser Entwurf basiert auf der Anforderungserhebung mit Geschäftsführern von Speditionsunternehmen. Eine Schwierigkeit dieses Ansatzes ist, dass die Schnittstellen und Wertflüsse nicht exakt spezifiziert werden können und die vorgestellte Methodik somit erweitert werden muss.

Zur Erweiterung des Geschäftsmodells wird aus diesem Grund die Erstellung einer Business-Architektur, die die relevanten Geschäftsprozesse einer Frachtenkooperation kleiner und mittlerer Spediteure im Teilladungssegment definiert, erfolgen. Diese Business-Architektur muss neben den individuellen Anforderungen der Speditionsunternehmen auch die systemrelevante Umwelt (beispielweise auf Basis gesellschaftlicher Megatrends) berücksichtigen. Sie wird so flexibel ausgestaltet, um ebenfalls an sich wandelnde Anforderungen der Stakeholder anpassbar zu bleiben. Die in der Business-Architektur definierten Geschäftsprozesse bilden die Basis für die sich anschließende Konzipierung der IT-Architektur für die optimierte Zentraldisposition.

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# Interruptibility and its Negative Impact on Graph Exploration Missions by a Team of Robots

**Hamido Hourani, Eckart Hauck and Sabina Jeschke**

**Abstract** Exploring an unknown graph has several fields of applications such as search and rescue operations. A team of robots is used to speed up these exploration missions; provided that they synchronize and coordinate their activities. Here, several conditions may limit the communication capabilities of robots which are crucial for coordination (e. g. high temperature). Therefore, a periodic rendezvous is needed as a work around in order to overlap their communication ranges. Attending these periodic rendezvous sessions requires that robots interrupt their current exploration progress periodically and traverse back to the rendezvous points (i. e. Interruptibility). During their trips to these points, the robots cross the explored part of the graph. Thus, they do not gain new knowledge about the graph. Furthermore, it increases the required time of exploration. Evaluating the impact of these interruptions on the exploration process through several experiments under different exploration strategies is the scope of this paper.

**Keywords** Robot Team · Rendezvous · Interruptibility · Graph Exploration

## 1 Introduction

Wallgrün [1] described the exploration process as a task of covering all accessible points in the workspace. Its purpose is either to generate a spatial map to be used later by other robots or to reach all accessible points in the workspace (e. g. cleaning mission). The shortage of priori knowledge about the target workspace had been used by [2] to distinguish the exploration process from the coverage process. Moreover, the outcome of the exploration process is the equivalent map of the explored spaces. This process has many purposes such as commercial interest [3], urban search and rescue [4], curiosity [5], cartography, or virtual reality. The used workspace in this paper is a static planar graph. Thus, the given graph maintains its structure during the exploration process.

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Multi-robot exploration has several advantages over a single robot exploration approach; speed up the exploration process, and avoid single point of failure, to name a few. To have these advantages, a coordination mechanism is crucial to distribute and merge the target graph among the team members. In order to coordinate, a communication approach is required. The communication is carried out either by following an indirect approach or a direct or both [6]. By indirect approach, robots communicate by sensing the effects of their colleagues such as dropped beacons. Sending and receiving information through a medium is termed as a direct approach which, in turn, is the considered approach in this paper.

A communication range which covers the entire target graph provides robots the ability to coordinate their exploration activities while they are exploring. However, many conditions limit the available range of communication among robots. These conditions are either because of the weak capabilities of robots [7], or because of the surrounding environments [8]. Due to these limitations on a communication range, a work around is needed to compensate this limitation impact on the coordination among robots.

Arkin and Diaz [9] addressed this limitation by using an anchored robot with which the other robots had to maintain a stable sight-line communication during the exploration. A similar approach was presented by Atay and Bayazit [10]. However, instead of using a single specialized anchor robot, each robot could be used as a network hub to pass messages to its colleagues. To increase the communication range, Duncan et al. [11] connected a robot by a rope (e. g. network cable) of length l with a base station, so it explores the area within distance l. When the robot reached the maximum distance, it had to return to its base. This rope approach is so-called Piecemeal Exploration approach [11]. Applying this approach means two constraints have to be taken into account: Continuity and Interruptibility. Continuity means a robot cannot jump between nodes on the graph; on the contrary it has to physically traverse a continuous path. Interruptibility means a robot has to interrupt its work to return to the base periodically (i. e. starting position, meeting point).

Instead of maintaining a permanent communication among the robots [9–11], robots can establish a temporary communication to coordinate, when needed. This strategy allows robots to move freely and utilizes them for exploration instead of reserving part of them as hub-like robots. Accordingly, robots should gather on a point at the same time to have an overlap in their communication ranges and thus to coordinate [12].

The process of achieving such a meeting either with pre-arrangement or without an arrangement is so-called rendezvous [13]. Aplern and Gal [13] classified rendezvous into two categories: asymmetric and symmetric rendezvous. Asymmetric rendezvous indicates that robots already know each other and they schedule a rendezvous before separation. For instance, robots start exploration from the same point and then separate. Symmetric rendezvous, on the other hand, does not indicate an arrangement before separation. For instance, robots start from different locations.

In this paper, we term the rendezvous which takes place according to an already scheduled meeting as Intentional Rendezvous. That is, it takes place according to a previous asymmetric rendezvous. On the other hand, the rendezvous which takes

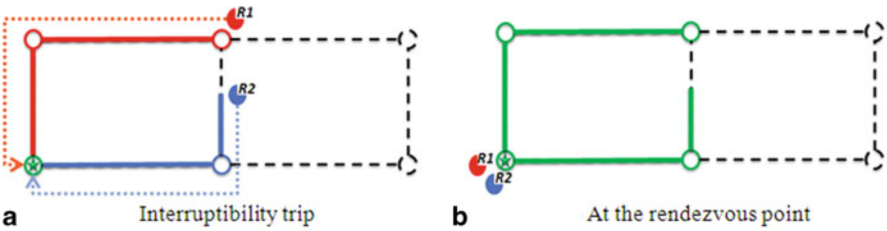


**Fig. 1** Negative (**a**) and positive impact (**b**) of Interruptibility on an exploration mission; Part **a** sketches two robots R1 and R2 which interrupted their exploration to attend a scheduled rendezvous. Both of them are going to re-traverse a path on their explored part of the graph (*dotted lines*). Part **b** sketches the outcome of attending the rendezvous where partial knowledge of both robots is merged and shared

place without a pre-arrangement is termed as Accidental Rendezvous. Attending the periodic rendezvous sessions inherits Interruptibility's behaviour from the Piecemeal Exploration approach. This inheritance indicates that robots have to interrupt their exploration progress to travel back to the rendezvous point. Because of the absence of a physical rope, the rendezvous approach differs from the piecemeal approach in that robots have the option to follow different paths instead of re-traversing the same path between its current position and the rendezvous point. Interruptibility has a positive impact on robots exploration because they get the chance to coordinate and exchange their partial knowledge [14] (c.f. Fig. 1b). But, it also contains a negative impact on robots because they do not gain any knowledge during the trip of Interruptibility. By trip we mean: crossing the already explored path between the current positions of robots to the rendezvous points (c.f. Fig. 1a).

Evaluating the negative impact of Interruptibility on graph exploration under limited direct communication constraint is the aim of this paper. Apart from that, the paper is organized as following: Problem description is covered in Sect. 2. Related works of mitigating Interruptibility is in Sect. 3. Section 4 is dedicated to evaluate Interruptibility's negative impact through several experiments. Challenges of mitigating this negative impact are the scope Sect. 5. Section 6 concludes the paper.

## 2 Problem Description

An algorithm of a naïve graph exploration approach under limited communication constraints is depicted in Algorithm 1. The presented pseudo-code depends on Intentional Rendezvous as a coordination strategy among robots.

**Algorithm 1** Naïve exploration approach

```
Input : Unknown Graph G and a team of robots R
Output: Explored Graph G' and a team of robots R
Begin
  time is initialized
  For each robot in R do
    If an ad-hoc set of robots is able to communicate Then
      Share partial knowledge of Explored G
      Distribute discovered Frontiers
      Schedule a rendezvous before separation
    End
    Explore the assigned frontier
  End
End
```

During the exploration mission, each robot tries to increase its knowledge about the unknown part of the graph. Thus, they are attracted to frontiers. A frontier is the border between an explored and a non-explored space. This exploration approach is firstly coined by Yamuchi [15] as Frontier-Based approach.

Once frontiers are distributed among robots, robots are separated to drive to their assigned frontiers. As a consequence, the communication range among them is broken. Thus, scheduling a rendezvous before separation is crucial to exchange the explored parts of the graph and to distribute the new discovered frontiers.

The time and location of the rendezvous are determined by the involved robots of that meeting. Several approaches are followed to schedule the rendezvous on the explored part of the graph. Keshmiri and Payandeh [16] used a regression route planar to find an optimise schedule among robots. Hoog et al. [17] selected rendezvous points closed to frontiers and the time was specified by multiplying it by a threshold.

After scheduling such a rendezvous, robots move to their assigned frontiers and explore the associated unexplored area behind these selected frontiers. While robots are exploring, they monitor their distance to the rendezvous point. Hence, they activate Interruptibility's behaviour to reach the rendezvous point on time. This behaviour is depicted on Algorithm 2.

**Algorithm 2** Pseudo-code of Interruptibility behaviour which is applied by individual robots

```
Input  : Robot's current position P_current ,
         The current time t_current
         Related rendezvous's position P_rendezvous ,
         Related rendezvous time t_rendezvous
Output : P_current = P_rendezvous and t_current = t_rendezvous
Begin
  Calcuate Time_To_Reach P_rendezvous
  If (t_rendezvous - t_current) = Time_To_Reach
     // activates Interruptibility's behaviour
     Interrupt the current robot's task
     Save robot's state
     Shortest Path between P_current and P_rendezvous
     Traverse the shortest path
  End
End
```

The robot follows always the shortest path between its current position and the rendezvous point. The current position of each robot is unknown to their colleagues because of the absence of communication among them. The rendezvous point, on the other hand, is known among robots because they agree on this point before separation.

During Interruptibility, the robot either re-traverses the same crossed path between the rendezvous point and its current position or follows a new path. For instance, it finds a shortcut to the rendezvous point while it is exploring its assigned area. Here, a shortcut is defined as a shorter path to the rendezvous point than its already crossed path.

Regardless of following the crossed path or a shortcut, the robot crosses an already explored area. This indicates that it does not gain new knowledge about the unexplored part of the graph during the trip of Interruptibility (i. e. a negative impact of Interruptibility). But once it reaches the rendezvous point, it adds the explored parts of its colleagues to its partial knowledge (i. e. a positive impact of Interruptibility). It is worth mentioning that this negative impact of Interruptibility could affect half of the robots' exploration time which is reserved to reach the rendezvous point.

## 3 Related Works on Mitigating Interruptibility's Negative Impact

Despite the fact that the rendezvous in robotics has got an intensive interest within the last two decades, it is seldom to find research works which address this negative impact of Interruptibility. The main reason of not handling Interruptibility is because of focusing on symmetric (i. e. accidental) rendezvous strategies. That is, how can a team of robots meet in unknown environment without any pre-arrangement?

The main research work which touched this negative impact indirectly is Hoog et al. [17]. There, robots were classified as an explorer and a relay. The explorer had the exploration mission while the relay robot had the mission of transferring the explorer knowledge to the command station. Thus, the explorer worked on an unknown part of the environment while the relay robot worked on the explored part of it. Both robots scheduled a rendezvous periodically before the separation.

Hoog et al. [17] tried to mitigate Interruptibility by selecting the rendezvous point close to the frontiers of the explorer. Moreover, the explorer could meet the relay robot before the scheduled rendezvous since the relay was just crossing explored spaces between two known points (rendezvous point and the command station).

This presented mitigation accumulates the negative impact of Interruptibility at the explorer side. That is, it has to cross more distance on the already explored area to meet the rely robot. Moreover, a part of the team (e. g. the relay robot) is dedicated only to cross the explored part of the environment. Thus, the negative impact of Interruptibility does not affect the relay robot.

In this paper, at the other side, the entire team members are utilized on exploring the given graph. Thus, the positive and the negative impact of Interruptibility have an effect on the individual behaviour of the involved robots.

## 4 Evaluating Interruptibility

### *4.1 Simulator Framework*

To implement the graph exploration mission by a team of robots, we have developed our own simulator which is based on MATLAB and by using MatlabBGL library [18]. This simulator is provided with several parameters which control the exploration behaviour, rendezvous' schedule, and frontiers; to name a few.

For the sake of simplicity, each vertex and edge of the graph has a unique identifier. But robots have to explore them to reveal these identifiers and the graph topology. The idea of using unique identifiers is to eliminate the ambiguity of matching discovered vertices and edge. Robots, in turn, have unique identifiers. On the contrary of the graph's identifiers, robots are aware of their colleagues' identifiers because they meet in advance at the starting point.

Each robot communicates with its colleagues once they are occupying the same point on the graph which is either on a vertex or an edge. Robots have four states to transfer between them. These states are sketched in Fig. 2.

Initially, the robots start with Merging and Coordination state since they are located at the same point. In addition to merge their partial knowledge about the graph, they distribute the frontiers among themselves. This step is achieved by electing a leader robot. This leader has the mission to assign each involved robot with a frontier. Moreover, it merges all constructed maps of the involved robots in a single coherent

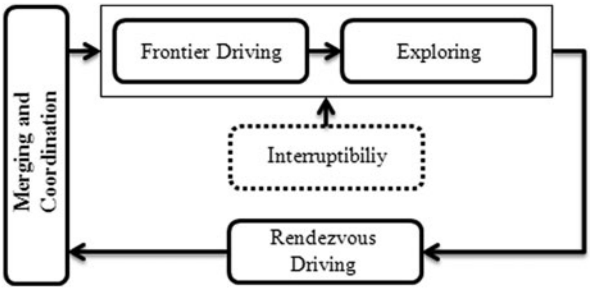


**Fig. 2** Robots' state according to the developed simulator

map. This merged map is distributed on the involved robots. The leader is a robot with the smallest identification number among the involved robots.

Frontier Driving is the next state where the robots move to their assigned frontier. Each robot follows the shortest path between its current positions to reach its assigned frontier. Once the robot reaches its assigned frontier, it starts its Exploring state. Within this state, the exploration is carried out by following the depth first search algorithm. While the robot is exploring, it keeps track of the discovered frontiers.

In order to transfer to the Rendezvous Driving state, each robot is triggered by an internal reminder (i. e. depicted as dotted rectangle in Fig. 2). It reminds the robot about the scheduled rendezvous by keeping track of the distance to the rendezvous point and its time. Hence, the robot starts its Interruptibility trip. Once it meets other robots, it transfers to the first state. That is, merging and coordination.

The progress of exploration is measured by steps. Within each step, robots make a single move on either an edge or a vertex. The robots always move and they never wait at any point on the graph. Thus, the robots must be punctual to attend any rendezvous. Otherwise, they miss the meeting which implies that they get only the negative impact of Interruptibility. For instance, a robot interrupts its exploration progress to attend a rendezvous, once it reaches the rendezvous point it does not meet its colleagues there.

## *4.2 Experimental Scenario*

Three types of scenarios are considered to evaluate the negative impact of Interruptibility. These scenarios are:

1. Single behaviour scenario: in this scenario, robots explore the target graph while they are not coordinating with each other; even when they meet. Therefore, Interruptibility does not have an impact on their exploration progress.
2. Accidental Rendezvous scenario: robots use only Accidental Rendezvous as a coordination strategy. Upon each rendezvous session, the involved robots merge their partial knowledge and distribute frontier among them through the elected

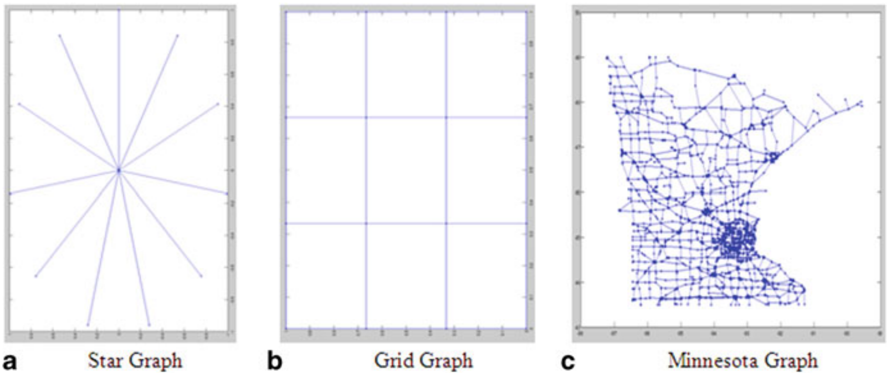


**Fig. 3** The used graph topologies within the experiment

leader robot. However, they do not schedule a rendezvous. Because of the absence of a scheduled rendezvous; Interruptibility does not have any impact.

3. Intentional Rendezvous scenario: in this scenario Interruptibility has an impact. It includes Accidental Rendezvous scenario but robots schedule a rendezvous after each rendezvous session.

For the sake of simplicity, we refer to the above scenarios as SINGLE, ACCIDT and INTERRP respectively. Based on each scenario, three graph topologies have been considered to be explored; these are:

1. Star Graph (c.f. Fig. 3a): This topology does not provide any shortcut between vertices and it neutralizes the benefits of starting to explore some frontiers than others. It is worth mentioning that picking up a frontier to explore is a random process. Therefore, regardless of which frontier the robot starts with, it traverses the same edge twice on this topology. This graph has 12 vertices and 22 edges with 10 distance unit as average edge weight.
2. Grid Graph (c.f. Fig. 3b): The usage of this topology has twofold goals. First, it has an organized structure with the required simplicity to track the individual exploration behaviour of the robots. Second, it provides several paths between vertices. Thus, some frontiers have more benefits than others which deviates the individual exploration behaviour of robots. The graph has 16 vertices and 64 edges with 4 distance unit as average edge weight.
3. Minnesota graph-like (c.f. Fig. 3c): As a map it consists of two main parts; the highly crowded part and the forked part. The crowded part provides a rich environment for Accidental Rendezvous because robots find many shortcuts. This part is depicted as bold spots on Fig. 3c. The forked part, on the other hand, provides a similar topology of the wheel graph which is a mitigated version of the star graph. Based on this mixture of topologies, the behaviour of the robots is deviated. Moreover, using Minnesota graph-like scales up the experiment because of the huge number of vertices (i. e. 2642) and edges (i. e. 6606) while it presents an abstract realistic experiment. Four distance unit is the average edge weight.

**Table 1** Results of running the exploration several times on three different topologies

| Graph | Scenario | Required steps to accomplish an exploration | | | | | | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | EXP1 | EXP2 | EXP3 | EXP4 | EXP5 | EXP6 | EXP7 | EXP8 | EXP9 | EXP10 | |
| Star | SINGLE | 354 | 354 | 354 | 354 | 354 | 354 | 354 | 354 | 354 | 354 | 354 |
| | ACCIDT | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 |
| | INTERRP | 166 | 166 | 166 | 166 | 166 | 166 | 166 | 166 | 166 | 166 | 166 |
| Grid | SINGLE | 289 | 294 | 294 | 289 | 283 | 300 | 288 | 284 | 288 | 289 | 289,8 |
| | ACCIDT | 165 | 265 | 217 | 139 | 150 | 188 | 263 | 214 | 222 | 260 | 208,3 |
| | INTERRP | 370 | 226 | 371 | 342 | 254 | 226 | 243 | 250 | 255 | 274 | 281,1 |
| Minnesota | SINGLE | 23741 | 23897 | 23623 | - | - | - | - | - | - | - | 23753,67 |
| | ACCIDT | 15018 | 14702 | 16094 | - | - | - | - | - | - | - | 15271,33 |
| | INTERRP | 9436 | 10343 | 8400 | - | - | - | - | - | - | - | 9393 |

On exploring the star and grid graph topologies, a team of five robots has been used while a team of 13 robots has been used on Minnesota graph-like. The reason of this deviation of the used number of robots is to adapt with size of the graph. Thus, it maintains a fairness level among the applied scenarios. For instance, if the number of robots is increased on the given grid graph then the probability of having Accidental Rendezvous sessions is increased. As a result, ACCIDT scenario shows better exploration performance than the other scenarios. On the other hand, if the number of robots is decreased on Minnesota graph-like then the probability of having Accidental Rendezvous sessions is decreased as well. Specifying the optimal number of robots to explore a given graph is out of the scope of this paper.

All robots start from the same point (i. e. vertex) at the same time and a successful exploration means all robots return back to the starting point while they cover the entire target graph. As a consequence, the required steps of accomplishing the exploration by the team are equal to the consumed steps of the slowest member (i. e. robot) of the team. Having an empty frontier list is the indicator that each robot uses to figure out its complete coverage of the graph.

## *4.3 Analysis of Experimental Results*

Table 1 shows the experimental results of running the exploration mission 10 times on the star and the grid graph under each scenario. Due to the required time and resources to accomplish an exploration on Minnesota graph-like, the number of these missions was reduced to three. This table is organized in four general columns. The first column contains the graph topology where the experiment ran. The second column is dedicated to the applied exploration scenario (e. g. INTERRP). The third column contains the required exploration steps to explore the given topology in the first column by following the given exploration scenario in the second column. The required steps are equal to the steps of the slowest robot of each team. The outcomes of the several experiments in the third column (i. e. EXP1, EXP2 . . . EXP10) are averaged in the fourth column. Thus, comparisons among scenarios can be easily derived.

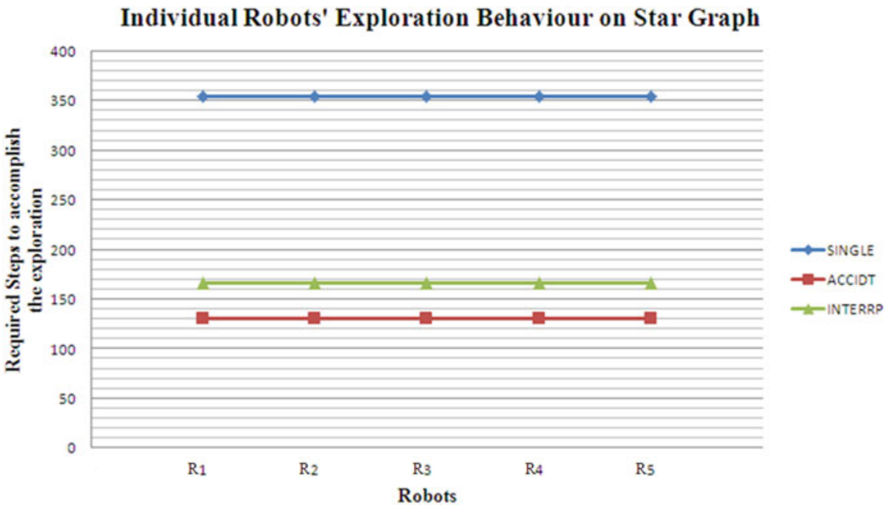


**Fig. 4** Running the three scenarios on the star graph topology by using a team of five robots

Considering the star and the grid graph topologies, the team of robots which applied ACCIDT scenario was faster in accomplishing the exploration than the other teams. However, this team of robots was the second best in accomplishing the exploration of Minnesota graph-like after the team of INTERRP scenario.

In order to explain the exploration behaviour of robots (i. e. as a team and as individuals) of each scenario, we consider EXP1 from Table 1 as an example. Figure 4 depicts the results according to the experiment EXP1 on the star graph topology while the experimental results of EXP1 on the grid and Minnesota graphs are depicted in Figs. 5 and 6 respectively.

On the star graph, the robots of SINGLE scenario consumed the highest number of steps to explore the graph. The explanation of this behaviour is because each robot has to traverse the entire graph by itself regardless of being explored by its colleagues. The benefits of a team of robots sharing their maps can be seen in ACCIDT and INTERRP. In comparison to the robots of ACCIDT, the INTERRP's robots were relatively slower. The reason of this slowness of the robots is the negative impact of Interruptibility. That is, the robots had to interrupt their exploration several times to traverse back to attend the rendezvous point. As a consequence, they crossed the same edge more than twice. This constraint of traversing back is relaxed in ACCIDT scenario.

It is worth mentioning that individual robots of each scenario consumed the same number of steps to explore the graph. The explanation of this behaviour comes from the star topology of the graph. In such a topology, robots traverse each edge at maximum twice (i. e. excluding INTERRP's robots because of Interruptibility) regardless of the selected frontier. Therefore, the randomness factor of selecting a frontier is neutralized. Moreover, the given topology does not provide any shortcuts between any two vertices. Hence, all robots of each scenario have the same behaviour and consumed the same number of steps.

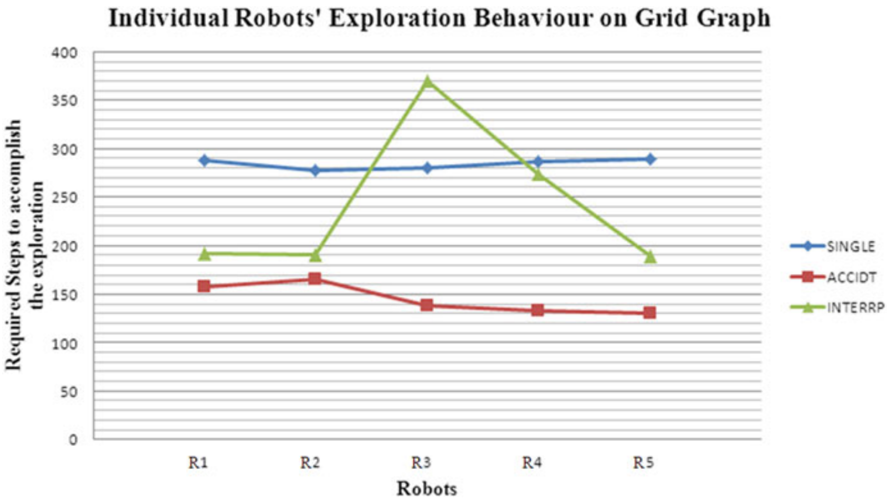


**Fig. 5** Running the three scenarios on the grid graph topology by using a team of five robots

Referring to the grid topology (c.f. Fig. 3); due to the random frontier selection and the grid topology of the graph, the individual robots of each scenario deviated in the required steps to accomplish the exploration. For instance, robots which selected a frontier that directed them inside the grid where faster to accomplish the exploration than the robots which selected circumference frontiers. This frontier classification is not applicable on the star topology graph; therefore, it does not have an influence on breaking the similarity of the required steps among robots of the same group.

Considering Robot 3 (R3) of INTERRP scenario, it showed an exploration behaviour which consumed more steps than any other robots of the three scenarios. The explanation of this behaviour is because of the type of frontiers which R3 got and its participation number of Intentional Rendezvous sessions. On the one hand, R3 picked up frontiers which are located at the circumference of the grid; thus, it did not find any shortcut to the rendezvous points. Based on that, R3 was bouncing between its selected frontier and its several rendezvous points. Thus, it consumed the maximum number of steps compared to its colleagues of INTERRP scenario. Most of the R3 Intentional Rendezvous had been taken place with R4. Accordingly, R4 had the same issue as R3; however, it was mitigated because of the type of frontiers which were internal frontiers in general.

On Minnesota graph-like topology, INTERRP scenario showed a better exploration performance than SINGLE and ACCIDT scenarios. The reason of this performance is because of the many branches and shortcuts which Minnesota topology has. Thus, robots could reach rendezvous points by following shorter paths than their already crossed paths. This advantage of having such a fork topology on INTERRP scenario is considered a disadvantage for ACCIDT scenario. That is, robots which only depend on Accidental Rendezvous as a coordination strategy have a lower chance to meet again accidently after their separation. R11 of ACCIDT scenario is

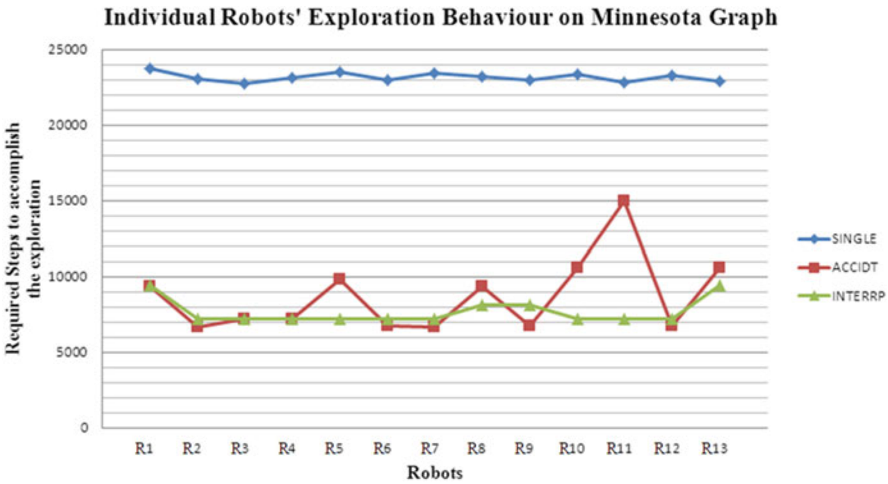


**Fig. 6** Running the three scenarios on Minnesota graph-like by using a team of 13 robots

a good example of such an isolated robot; thus, it consumed more steps to explore what had been explored by its colleagues.

### *4.4 Summary*

Despite the fact that Accidental Rendezvous shows a better performance than Intentional Rendezvous, it does not have any guarantee that robots will meet again. Thus, the overall performance will be degraded towards the single robots performance. This case has clearly appeared in a forked planar graph where robots get distributed on branches and then they follow the single exploration behaviour. Thus, they just get the benefits of distributing frontiers of the starting point among themselves equally at the beginning of the exploration mission.

Accordingly, Intentional Rendezvous is crucial to have a sustainable performance; even with its associated negative impact. However, a mitigation of this negative impact should be introduced to enhance the performance of this rendezvous strategy while its positive impact is maintained.

## 5 Challenges of Mitigating Interruptibility's Negative Impact

Revealing the current position of each robot is the key to mitigate the negative impact of Interruptibility. By having these positions, robots can meet at a point near to their positions instead of returning back to the far rendezvous point. However, such an accurate knowledge about positions is not possible.

During Interruptibility, robots cross a path between two points: the source points which are their current positions and the destination points which are their target rendezvous points. The source points distinguish themselves from the destination points in that they are unknown to the other robots due to the broken communication channel among them. Destination points (i. e. rendezvous point), on the other hand, are known because robots agree on the location of these points before they separate. To minimize the associated time of Interruptibility, robots have to follow the shortest path between their current locations and their rendezvous points. This path is either the same crossed path between the rendezvous point and the current position of the robot or it is a shortcut. In both cases, it is located on the explored part of the graph.

As a consequence, to mitigate the negative impact of Interruptibility two challenges have to be considered; these challenges are:

1. Forecasting the current positions of the considered robots (i. e. the source points).
2. Forecasting the followed path between the estimated robots' positions and their target rendezvous points.

Generally, handling the first challenge is a prerequisite to handle the second one. However, this dependency between challenges can be relaxed under some conditions. For instance, a robot could depend on the rendezvous point to forecast from which direction the other robots will reach it.

By addressing these challenges, a robot can estimate the exploration progress of its colleagues. Thus, it has the ability to meet them accidentally on a point close to their current positions; this point is on the common explored part of the graph.

## 6 Conclusion

Intentional Rendezvous has a crucial role to maintain the coordination among explorer robots under limited communication constraints. But interrupting the current exploration progress to attend the scheduled rendezvous has negative impact on the exploration mission. The reason of this impact is because the robots do not gain new knowledge about the unexplored part of the graph during the trip of Interruptibility.

Emphasising this impact is elaborated through several experiments on three different graph topologies. According to the result, the robots which applied Intentional Rendezvous exploration behaviour were slower than the robots which only applied Accidental Rendezvous due to the absence of Interruptibility. In spite of this, having Intentional Rendezvous as coordination strategy provides a sustainable performance for the exploration mission; the simulated experiment on Minnesota graph-like topology supports this conclusion.

Yet, the negative impact of Interruptibility has to be mitigated in order to enhance the performance. In addressing this negative impact requires two challenges to be handled: forecasting the current position of robots and forecasting their crossed path to reach the rendezvous point. To the best of our knowledge mitigating this negative impact on exploration missions under limited communication constraints has not been addressed by any research work yet. Addressing this negative impact is a subject to our further research works.

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# Serendipity Rendezvous as a Mitigation of Exploration's Interruptibility for a Team of Robots

**Hamido Hourani, Eckart Hauck and Sabina Jeschke**

**Abstract** Dependence on a team of robots to carry out the exploration missions has many benefits such as speeding up the missions; provided that the coordination among robots is maintained. Many circumstances can limit the communication, which is crucial for the coordination among robots (e. g. impenetrable barriers, high temperature etc.). A periodic rendezvous strategy is considered in this paper as a work around in order to overlap communication ranges of the robots. Attending these periodic rendezvous sessions requires that the robots interrupt their current exploration progress periodically and traverse back to the rendezvous points (i. e. Interruptibility). During their trips to these points, they do not gain new knowledge since they cross already explored parts of the area. Therefore, using rendezvous strategies improves the team behavior but has a negative impact on the time efficiency. The contribution of this paper is to mitigate this negative impact of Interruptibility on explorations while maintaining the coordination among robots. The mitigation algorithm is evaluated on several graphs and its performance is compared with other rendezvous approaches where the results are promising.

**Keywords** Robot Team · Rendezvous · Interruptibility · Graph Exploration

## 1 Introduction

Exploration is defined as the process of visiting all accessible points of the target workspace [1]. The outcome of the exploration is the equivalent spatial map of the explored area. The shortage of priori knowledge about the workspace distinguishes exploration missions from the coverage missions (e. g. cleaning a room) [2]. Exploration has many purposes such as commercial interest [3], urban search and rescue [4], curiosity [5], and cartography. The used workspace in this paper is a static planar graph. Here, static means that the graph maintains its structure during the exploration process.

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Coordinating the robots' activities while exploring and having a coherent knowledge about the exploration progress are the keys to gain the benefits of team work. As a prerequisite, a communication approach is required. The communication is carried out either by following an indirect communication approach or a direct approach or both [6]. By an indirect approach, robots communicate by sensing the effects of their colleagues such as dropped beacons. Sending and receiving information through a medium is termed as a direct approach which is the considered approach in this paper. This is because of its suitability as a coordination tool among a team of robots [6]. A communication range which covers the entire target graph provides robots with the ability to coordinate their activities while they are exploring. However, many conditions limit this range. These conditions are either because of the weak capabilities of robots [7] or due to the surrounding environments [8]. Thus, a work around is needed to compensate this impact on the coordination among robots.

Two work-around approaches have been introduced to address this limitation. The first approach is intended to maintain a persistent communication among robots. This approach is carried out by having hub-like robots to pass messages among their colleagues [9] or by depending on a piecemeal exploration approach. That is, robots are connected by a rope either between themselves or with a base station. Such an approach inherits two constraints [10]: Continuity and Interruptibility. Continuity means a robot has to physically traverse a continuous path. Interruptibility means a robot has to interrupt its work to return to the base periodically (i. e. starting position, meeting point).

The second work-around approach achieves the communication among robots when needed. This approach allows robots to move freely and utilizes them for exploration instead of reserving a part of them as hub-like robots. Accordingly, robots should gather at a point at the same time to have an overlap in their communication ranges and thus to coordinate [11].

The process of achieving such a meeting either with or without a pre-arrangement is a so-called rendezvous [12]. Aplern and Gal [12] classified rendezvous as asymmetric and symmetric. Asymmetric rendezvous indicates that robots already know each other and they schedule a rendezvous before separation. Symmetric rendezvous, on the other hand, does not indicate an arrangement before separation.

In this paper, we term the rendezvous which takes place according to an already scheduled meeting as Intentional Rendezvous. That is, it takes place according to a previous asymmetric rendezvous. On the other hand, the rendezvous which takes place without a pre-arrangement is termed as Accidental Rendezvous. Attending the periodic rendezvous sessions inherits the Interruptibility behaviour from the piecemeal exploration approach. Here, robots have to interrupt their exploration progress to travel back to the rendezvous point. Because of the absence of a physical rope, the rendezvous approach differs from the piecemeal approach in that the robots have the option to follow different paths instead of re-traversing the same path between their current positions and the rendezvous points. Interruptibility ensures the occurred communication; therefore, it has a positive impact on robots exploration because they get the chance to coordinate and exchange their partial knowledge [13] (c.f. Fig. 1b). However, it also contains a negative impact on the robots because they do not gain any knowledge during the trip of Interruptibility. By trip we mean: crossing

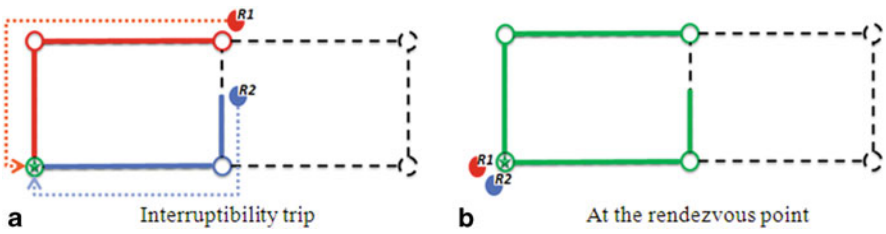


**Fig. 1** Part **a** sketches two robots *R1* and *R2* which interrupted their exploration to attend a scheduled rendezvous. Both of them are going to re-traverse a path in their explored part of the graph (*dotted lines*). Part **b** sketches the outcome of attending the rendezvous where partial knowledge of both robots is merged and shared

the already explored path between the current positions of robots to the rendezvous points (c.f. Fig. 1a).

The contribution of this paper is to mitigate this negative impact of Interruptibility on graph explorations while maintaining its positive impact. The algorithm behind this mitigation is evaluated by running it on several basic graphs and on a complex graph (i. e. Minnesota topology) and compared with other rendezvous approaches. The rest of the paper is organized as following: Problem description and related works are covered in Sect. 2. The description of the algorithm is in Sect. 3. Section 4 is for evaluating the algorithm and Sect. 5 concludes this paper.

## 2 Problem Description

Algorithm 1 presents the pseudo code of the graph exploration approach through Intentional Rendezvous.

**Algorithm 1** *Naïve exploration approach*

```
Input : Unknown Graph  G  and a team of robots R
Output: Explored Graph G'  and a team of robots R
Begin
  time is initialized
  For each robot in R do
    If an ad-hoc set of robots is able to communicate Then
      Share partial knowledge of Explored G
      Distribute discovered Frontiers
      Schedule a rendezvous before separation
    End
    Explore the assigned frontier
  End
End
```

During the exploration mission, each robot tries to increase its knowledge about the unknown part of the graph. Thus, they are attracted to frontiers. A frontier is the border between an explored and a non-explored space. This exploration approach is firstly coined by Yamuchi [14] as Frontier-Based approach.

Once frontiers are distributed among robots, the robots are separated to drive to their assigned frontiers. As a consequence, the communication range among them is broken. Thus, scheduling a rendezvous before separation is crucial to exchange the explored parts of the graph and to distribute the new discovered frontiers.

The time and location of the rendezvous are determined by the involved robots of that meeting. Several approaches are followed to schedule the rendezvous on the explored part of the graph. Keshmiri and Payandeh [15] used a regression route planner to find an optimised schedule among robots. Hoog et al. [16] selected rendezvous points close to frontiers and the time was specified by multiplying it by a threshold. The used approach by this paper is described in Sect. 3.1.

After scheduling such a rendezvous, robots move to their assigned frontiers and explore the associated unexplored area behind these selected frontiers. While robots are exploring, they monitor their distance to the rendezvous point. Hence, they activate Interruptibility behaviour to reach the rendezvous point on time (c.f. Algorithm 2).

**Algorithm 2** *Interruptibility approach*

**Input** : Robot's current position $P_{current}$ ,
The current time $t_{current}$
Related rendezvous's position $P_{rendezvous}$ ,
Related rendezvous time $t_{rendezvous}$

**Output** : $P_{current} = P_{rendezvous}$ and $t_{current} = t_{rendezvous}$

**Begin**
  **Calcuate** *Time_To_Reach* $P_{rendezvous}$
  **If** $(t_{rendezvous} - t_{current}) = Time\_To\_Reach$
    // activates Interruptibility's behaviour
    **Interrupt** the current robot's task
    **Save** robot's state
    **Shortest Path** between $P_{current}$ and $P_{rendezvous}$
    **Traverse** the shortest path
  **End**
**End**

To minimize the associated time of Interruptibility, robots follow the shortest path between their current locations and their rendezvous points. The current locations distinguish themselves from the rendezvous points in the fact that they are unknown to the other robots due to the broken communication channel among them. Rendezvous points, on the other hand, are known because the robots agree on the location of these points before they separate.

During Interruptibility, the robot either re-traverses the same crossed path between the rendezvous point and its current position or follows a new path. For instance, it finds a shortcut to the rendezvous point while it is exploring its assigned area. Here, a shortcut is defined as a shorter path to the rendezvous point than its already crossed path.

Regardless of following the crossed path or a shortcut, the robot crosses an already explored area. Thus, it does not gain new knowledge about the unexplored part of the graph during this trip. Once it reaches the rendezvous point, it adds the explored parts of its colleagues to its partial knowledge (c.f. Fig. 1). It is worth mentioning that this negative impact of Interruptibility could affect half of the robots' exploration time which is reserved to reach the rendezvous point.

### *2.1 Related Works of Mitigating Interruptibility*

Despite the fact that the rendezvous in robotics has got an intensive interest within the last two decades, research works which address this negative impact of Interruptibility are rare. The main reason of not handling Interruptibility is because of focusing mainly on symmetric (i. e. accidental) rendezvous strategies. That is, how can a team of robots meet in an unknown environment without any pre-arrangement?

The main research work which touched this negative impact indirectly is given by Hoog et al. [16]. There, robots were classified as an explorer and a relay. The explorer had the exploration mission while the relay robot had the mission of transferring the explorer knowledge to the command station. Accordingly, the explorer worked on an unknown part of the environment while the relay robot worked on the explored part of it. Both robots scheduled a rendezvous periodically before the separation. The negative impact of Interruptibility is mitigated by selecting the rendezvous point close to the frontiers of the explorer.

Following that mitigation approach [16] accumulates the negative impact of Interruptibility on a part of the team (i. e. the relay robot) while it mitigates this negative impact on the other part - the explorer robot in this case. As a consequence, it is not applicable if the entire team is devoted to explore the given unknown graph which is the case of this paper.

To the best of our knowledge, we are the first research group who highlights this problem and mitigates it under limited direct communication constraints.

## 3 Serendipity Rendezvous

Serendipity is derived from the Arabic word Sarandib which was used to label Sri Lanka. It got the meaning of fortunate coincidence because it was borrowed from a Persian fairy tale which is about a trip between the Middle East and Sarandib [17].

**Table 1** Comparison among the three rendezvous approaches

| | Accidental | Intentional | Serendipity |
|---|---|---|---|
| Rendezvous arrangement | Without an arrangement | With an arrangement | Mixed |
| Rendezvous point | Any place on the graph | Only on the common explored part of the involved robots | Only on the explored part of Serendip robot ($\boldsymbol{R}_S$) |
| Rendezvous time | Not applicable | Scheduled | Scheduled only by $\boldsymbol{R}_S$ |
| Pre-condition | None | It is based on a previous Accidental or Intentional Rendezvous | The rendezvous takes place during Interruptibility trip of $\boldsymbol{R}_S$ |
| Punctuality of the involved robots | Not applicable | All involved robots have to be punctual on attending the rendezvous | This property is applicable only on $\boldsymbol{R}_S$ |
| Post-conditions | Schedule Intentional Rendezvous before separation | Schedule Intentional Rendezvous before separation | (1) $\boldsymbol{R}_S$ has to attend its original Intentional Rendezvous session. (2) All participating robots of Serendipity Rendezvous should schedule Intentional Rendezvous before separation |

During this trip between these two known points, several fortunate discoveries took place to the hero of the story.

Like the hero of that story, during Interruptibility robots are crossing a path between two known points. Unlike the story, they do not make new discoveries during their trips since they cross already explored paths. But, the only fortunate coincidence which the robots can have is to meet their colleagues during their Interruptibility trips to the rendezvous points. Such a fortunate coincidence forms the core concept of the proposed rendezvous approach; the so-called Serendipity Rendezvous. Any robot which searches for its fortunate coincidence during its Interruptibility trip is termed as Serendip Robot $R_S$.

Serendipity Rendezvous is a mixture of Intentional and Accidental Rendezvous strategies. It takes from Intentional Rendezvous the pre-arrangement of the meeting. This meeting is only arranged by Serendip Robot. Therefore, it is located on the explored part of this robot. On the other side, Serendipity Rendezvous takes from Accidental Rendezvous the accidentally meeting among robots (i. e. excluding Serendip Robot which has already arranged the meeting).

Accordingly, Serendipity Rendezvous forms two viewpoints about the meeting. According to Serendip Robot, it is an Intentional Rendezvous because this robot is aware of the location and the time of the meeting. On the other side, it is considered as Accidental Rendezvous by the other participating robots because they are unaware of the arranged meeting. A comparison between these rendezvous strategies is clarified in Table 1.

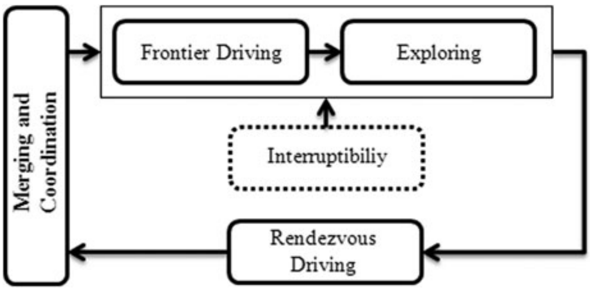


**Fig. 2** Robots' state according to the developed simulator

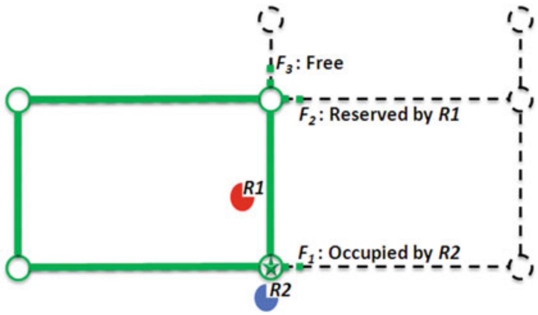


**Fig. 3** The frontier ($F_1$) is tagged as occupied because $R_2$ is standing at its vertex. $F_2$ is tagged as reserved because $R_1$ is going to reach it and then explore it. Once $R_2$ reaches $F_2$, it changes the tag to Occupied. $F_3$, on the other hand, is tagged as free because no robot is targeting it

Serendipity Rendezvous works as an optimization layer above Intentional Rendezvous. Therefore, describing it requires firstly introducing the exploration behavior of robots according to Intentional Rendezvous.

### *3.1 The Exploration Behavior of Robots*

Each robot communicates with its colleagues once they occupy the same point on the graph which is either on a vertex or an edge. Robots have four states to transfer between them (c.f. Fig. 2).

Initially, robots start with Merging and Coordination state since all robots are located at the same point. In addition to merge their partial knowledge about the graph, they distribute the frontiers among themselves. This step is achieved by electing a leader robot (i. e. the robot with the smallest ID). This leader has the mission to assign each involved robot with a frontier. Accordingly, frontiers are tagged with one of the following three tags: free, reserved and occupied. Free indicates that this frontier has not assigned to any robot yet. On the contrary, occupied indicates that this frontier is under exploration by a robot. That is, the robot is standing at the vertex of the considered frontier. Reserved as a tag means that this frontier is going to be explored once the responsible robot reaches it (c.f. Fig. 3).

After distributing the frontiers, the process of scheduling the next rendezvous session is carried out by the elected leader robot. This process is a part of the Merging and Coordination state. In this paper, the rendezvous point is determined by considering three strategies: (1) The attractiveness factor (2) the closest common vertex and (3) the vertex with maximum number of frontiers.

The attractiveness factor is followed if one of the vertices attracts more robots than other vertices. This indicates that the larger number of the involved robots is going to that vertex. In case of not, then the strategy of the closest common vertex is followed. This common vertex has to be equidistant to the larger set of the assigned vertices (i. e. the vertices which have been distributed on the involved robots). Furthermore, this vertex has to be located on the common path to reach that set of vertices. If the second strategy is not applicable, then the rendezvous point is the vertex with the maximum number of attached frontiers (i. e. the third strategy). This vertex has to belong to the set of the assigned vertices.

The rendezvous time, on the other side, is determined by considering two parameters. The first parameter catches the required time to cross the distance between the agreed rendezvous point and the current standing point of the involved robots of this meeting. The second parameter is a threshold which is used to provide the robots with a time margin to utilize it in further exploration. According to these parameters, the rendezvous time is calculated as following:

$$Rendezvous_{Time} = (FirstParameter * 2) + SecondParameter$$

*Frontier Driving* (c.f. Fig. 2) is the next state where the robots move to their assigned frontier. Each robot follows the shortest path between its current position and the assigned frontier. Once the robot reaches its assigned frontier, it starts its Exploring state. Within this state, the exploration is carried out by following the depth first search algorithm. While the robot is exploring, it keeps track of the discovered frontiers.

In order to transfer to the Rendezvous Driving state, each robot is triggered by an internal reminder. This reminder (i. e. Interruptibility) is depicted as dotted rectangle in Fig. 2. It consists of two sequenced notifications. The first notification (i. e. the initial notification) triggers the considered robot to plan its trip to the rendezvous point. For instance, the robot starts the required calculation to specify the followed path to the rendezvous point and when it exactly begins the Interruptibility trip. The initial notification is activated once the robot passes half of the required time to the scheduled rendezvous. That is:

$$Initial\_Notification = Rendezvous_{Time}/2$$

The second notification is to trigger the robot to follow the drawn plan (i. e. the actual reminder). The actual notification could be included in the initial notification, if the robot has to carry out the plan immediately. Once this robot meets other robots, it transfers to the Merging and Coordination state.

**Table 2** The description of the statistical data which each robot holds about its colleagues

| Statistical data | Attributes | Description |
|---|---|---|
| Interruptibility reminder | Wake Up; Snooze | It holds the cases of the actual notification being included in the initial one (i. e. Wake Up) and being separated (Snooze) |
| Rendezvous type | Accidental; Intentional | It holds the number of Accidental Rendezvous which the robot encountered. It implies the topology which this robot worked on it. |
| Robot rendezvous action | Attending; Delegating; Dropping | It holds the cases of attending the scheduled rendezvous or not {Delegation and Dropping} |
| Path tracking | Old Path; New Path | It holds the cases of re-traversing the same path or following a shortcut |

Besides merging the constructed maps of the involved robots, this state includes merging the lists of discovered frontiers and the scheduled rendezvous. Moreover, the statistical data which each robot has collected about its colleagues is merged. These statistical data are covered in Table 2. After merging the data of each list, they are distributed on the involved robots.

### *3.2 Algorithm Description*

Finding a path where a robot meets its colleagues according to Serendipity Rendezvous approach is the aim of this algorithm (c.f. Algorithm 3). This path is so called the serendipity path.

Applying the serendipity algorithm requires a pre-condition from Serendip Robot $R_S$. This precondition is to have a time space between the initial notification of Interruptibility and the actual one. Thus, the robot is able to carry out the serendipity manoeuvre. Otherwise, it has to follow the shortest path directly. This time space is controlled by MANOEUVRE_THRESHOLD.

In order to have a serendipity path, $R_S$ tries to find a set of valid alternative paths between its current position and the rendezvous point. Here, a valid path is the path which is crossed by the robot without missing the scheduled rendezvous.

In addition to its alternative paths, $R_S$ forecasts the crossed paths of selected robots. The common factor of these selected robots is that their initial notification is activated. This information about their initial notifications is fetched from the list of the scheduled rendezvous.

**Algorithm 3** *Pseudo code of the serendipity algorithm*

```
Input : A team of robots R
        Current positions P_current , and time t_current
        Rendezvous's positions P_rendezvous , and time t_rendezvous
        Shared Data
Output: Add a serendipity rendezvous to the rendezvous list
Begin
  FOR each robot in R do
     IF Interruptibility Reminder is activated THEN
        Calculate Time_To_Reach P_rendezvous
        ActualReminder := (Time_To_Reach + t_current ) - t_rendezvous
        IF ActualReminder > MANOEUVRE_THRESHOLD THEN
           Find AltPaths //paths between P_current and P_rendezvous
           Estimate relevant robots' paths
           Probability of following the estimated paths
           IF intersect(AltPaths, estimatedPaths) THEN
              Track positions of relevant robots
              Draw Serendipity Path
              Generate Serendipity Rendezvous
           END
        ELSE
           //Follow Usual Intentional Rendezvous Steps
        END
     END
  END
END
```

Estimating a crossed path requires the existence of two sets of end-points: source and destination points. Source points are equivalent to the standing points of the selected robots which are unknown to $R_S$. Destination points, in turn, are the rendezvous points which $R_S$ fetches from the rendezvous list.

To overcome the unknown points, $R_S$ depends on the assigned frontiers of the selected robots to draw potential crossed paths (c.f. Fig. 4). This set of estimated paths is a subject of uncertainty because they are constructed on the basis of partial information (i. e. not updated list). Furthermore, the selected robots could follow shortcuts or delegate the rendezvous. That is, if two robots accidently meet while they are going to the same rendezvous point to meet others; they delegate one of them to attend that meeting while the other robot continues its exploration.

Handling uncertainty by deriving new information from partial one is carried out mainly by Hidden Markov Model and Bayesian Network approaches [18]. Approaches of Bayesian Networks distinguish themselves from Hidden Markov Model by their efficiency on handling the causal dependencies between events [19]. In addition to this efficiency, Bayesian Network provides a compact representation of

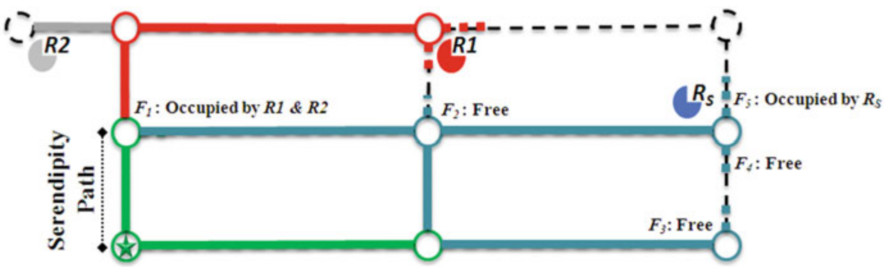


**Fig. 4** The *green* is the shared part of the involved robots while the robot colour indicates its own explored path. $R_S$ estimated the crossed path of *R1* by depending on the status of $F_1$. The frontiers are according to $R_S$ list

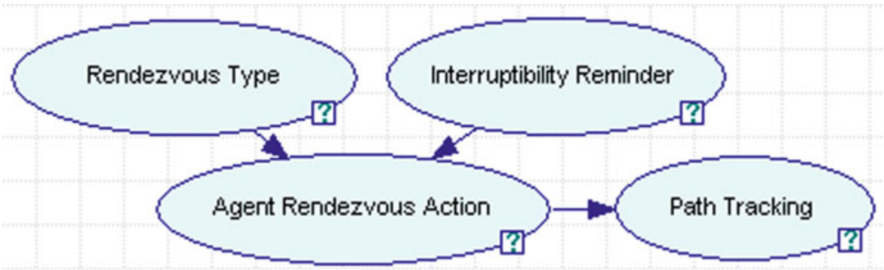


**Fig. 5** The constructed Bayesian Network to handle the uncertainty of the forecasted path of each considered robot. Parameters are listed in Table 2

knowledge and it combines two solid mathematical areas: graph and probability theories [20].

In this paper, Bayesian Network is applied to define the causal relationships between the exploration events of robots and to model a priori knowledge (i. e. statistical data) which each robot has about its colleagues. These statistical data are covered in Table 2. By depending on these casual dependencies, $R_S$ deduces the probability of the estimated path to be followed. Figure 5 depicts the constructed model of Bayesian Network.

The model consists of four variables and 11 parameters (note Table 2) where the variable *Interruptibility Reminder* is used as an evidence and Path Tracking is used as the target variable. This model is fed by statistical data which robots gather about their colleagues during the periodic Intentional Rendezvous rounds. The reasoner depends on the posterior probability distribution [20].

The middle variable (i. e. Robot Rendezvous Action) in Fig. 5 contains the probability of attending, dropping and delegating the rendezvous of each robot. This variable depends conditionally on two variables. The upper left variable (i. e. Rendezvous Type) which specifies the probability of Accidental Rendezvous which the considered robot has encountered; a higher probability of Accidental Rendezvous indicates a higher probability of delegation cases. The second upper variable (i. e.

Interruptibility Reminder) has two attributes: wake up and snooze. A higher probability of snoozing implies a higher probability of not attending the rendezvous either because of delegation or dropping. Furthermore, it has a strong indication that the robot follows shortcuts. Thus, the estimated path is not valid. On the other hand, responding to the initial reminder immediately increased the probability of reaching the rendezvous point by re-traversing the already crossed path.

Back to Algorithm 3, in order to decide which path of the set of alternative paths is the candidate serendipity path, an intersection between the alternative paths and the estimated crossed paths – which have higher probability to be valid - is carried out. Following that, the concrete sequence of positions of the selected robots is tracked by $R_S$. This tracking is calculated reversely by starting at the rendezvous point. By revealing sequence positions of the resulted set of robots, $R_S$ draws its serendipity path to meet some of these robots on their estimated positions.

This serendipity path is encapsulated as a rendezvous session and added to the list of scheduled rendezvous. Because the rendezvous time of this new record is the nearest time within the schedule, the robot considers it first. After attending this Serendipity Rendezvous, the robot considers its original scheduled Intentional Rendezvous. This algorithm works as an optimization layer above Intentional Rendezvous approaches. The complexity of this algorithm is dominated by the complexity of Dijkstra Algorithm (i. e. $O(|E|+|V|\log|V|)$ which is used to find the set of alternative paths [21]. Considering the number of robots $N$, the complexity of the presented algorithm is $O(N(|E|+|V|\log|V|))$. $E$ stands for edges and $V$ for vertices which form the given graph.

## 4 Evaluation of Serendipity

To evaluate the effectiveness of Serendipity Rendezvous approach, comparisons with Accidental and Intentional rendezvous approaches are carried out. These comparisons took place in our developed simulator which is based on MATLAB and by using MatlabBGL library [22] and Bayes Net Toolbox [23]. This simulator is provided with several parameters which control the exploration behaviour and the rendezvous schedule; to name a few. These parameters are fed either by deterministic or randomized inputs.

For the sake of simplicity, each vertex and edge of the graph has a unique identifier. However, robots have to explore them to reveal these identifiers. Before this exploration, robots are not aware of their existence and of the graph topology. This unique identifier feature helps the robots in merging their partial knowledge about the graph to get a single coherent graph. Thus, the ambiguity of matching vertices and edges is eliminated. Robots, in turn, have also unique identifiers and they are aware of their colleagues' identifiers because they meet in advance at the starting point.

The progress of the exploration is measured by steps. Within each step, robots make a single move on either an edge or a vertex. The robots always move and they never wait at any point on the graph. Therefore, the robots must be punctual to attend any scheduled rendezvous. Otherwise, they miss the meeting. As a result, the robot crosses a distance on the explored area without gaining any knowledge.

## *4.1 Experimental Setup*

Three graph topologies are considered to evaluate the presented algorithm. These topologies are:

1. Star Graph (Fig. 6a): This topology does not provide any shortcut between vertices and it neutralizes the benefits of starting to explore some frontiers rather than others. It is worth mentioning that picking up a frontier is a random process. Thus, regardless of which frontier the robot starts with, it traverses the same edge twice on this topology. As the structure of the graph, it has 12 vertices and 22 edges with 10 distance units as an average edge weight.
2. Grid Graph (Fig. 6b): The usage of this topology has twofold goals. First, it has an organized structure with the required simplicity to track the individual exploration behavior of the robots. Second, it provides several paths between vertices. Thus, some frontiers have more benefits than others. This graph consists of 16 vertices and 64 edges with 4 distance units as an average edge weight.
3. Minnesota Graph (Fig. 6c): As a map it consists of two main parts; the highly crowded part and the forked part. The crowded part provides a rich environment for finding many shortcuts. This part is depicted as bold spots on Fig. 4c. The forked part, on the other hand, provides a similar topology of the wheel graph which is a mitigated version of the star graph. Moreover, using Minnesota graph scales up the exploration experiment because of the huge number of vertices and edges and it presents an abstract realistic experiment. As the structure of the graph, it has 2642 vertices and 6606 edges with 4 distance units as an average edge weight.

A team of five robots has been used to explore the star and grid graph topologies, while a team of 13 robots has been used on Minnesota graph. The reason for this deviation of the used number of robots is to adapt to the graph size. Thus, it maintains a fairness level among the three types of the applied scenarios. For instance, if the number of robots is increased on the grid graph then the probability of having Accidental Rendezvous sessions is increased. As a result, it will show better exploration performance than the other approaches. On the other hand, if the number of robots is decreased on Minnesota graph then the probability of having Accidental Rendezvous sessions will be decreased as well. Specifying the optimal number of robots to explore the given graph is out of the scope of this paper.

All robots start from the same point (i. e. vertex) at the same time and a successful exploration means all robots return back to the starting point while they cover the entire target graph. As a consequence, the required steps of accomplishing the exploration by the team are equal to the consumed steps of the slowest member

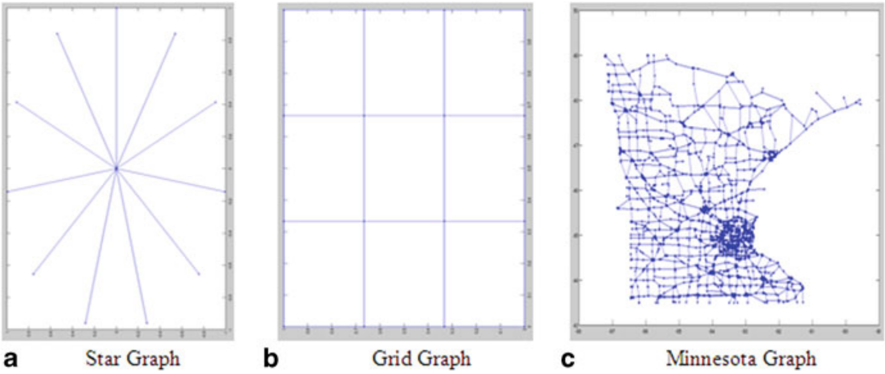


**Fig. 6** The used graph topologies within the experiment

**Table 3** Results of running the different approaches on the given topologies

| Rendezvous approach | Graph topology | | |
|---|---|---|---|
| | Star (5 robots) | Grid (5 robots) | Minnesota (13 robots) |
| Accidental | *130 steps* | *165 steps* | 15,018 steps |
| Intentional | 158 steps | 186 steps | 8746 steps |
| Serendipity | 158 steps | 254 steps | *8668 steps* |

(i. e. robot) of the team. Having an empty frontier list is the indicator that each robot uses to figure out if it has completed the coverage of the graph.

In order to have the same simulator conditions among the rendezvous approaches, the same sequence of random numbers is re-generated for each rendezvous approach. As a consequence, the performance of the rendezvous approaches is differentiated according to the exploration activities of robots and not by applying different simulator conditions.

## *4.2 Analysis of Experimental Results*

Table 3 shows the results of running the rendezvous approaches on different graph topologies.

Considering the experiments on the star and grid graphs, the team of robots which applied Accidental Rendezvous approach was faster in accomplishing the exploration than other teams. However, this team was the slowest team when it was applied on Minnesota graph. In this topology, the consumed steps of the Intentional and Serendipity Rendezvous teams were converged. The exploration behavior of individual robots within each rendezvous approach on star, grid and Minnesota are depicted in Figs. 7, 8 and 9 respectively. In these figures, ACCIDT stands for Accidental, INTENT for Intentional and SEREND for Serendipity Rendezvous.

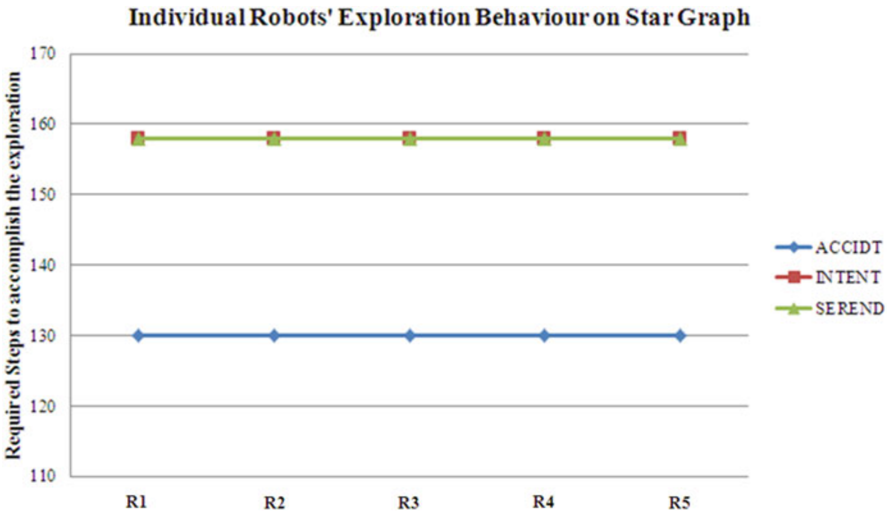


**Fig. 7** Individual robots' exploration behaviour on the star graph

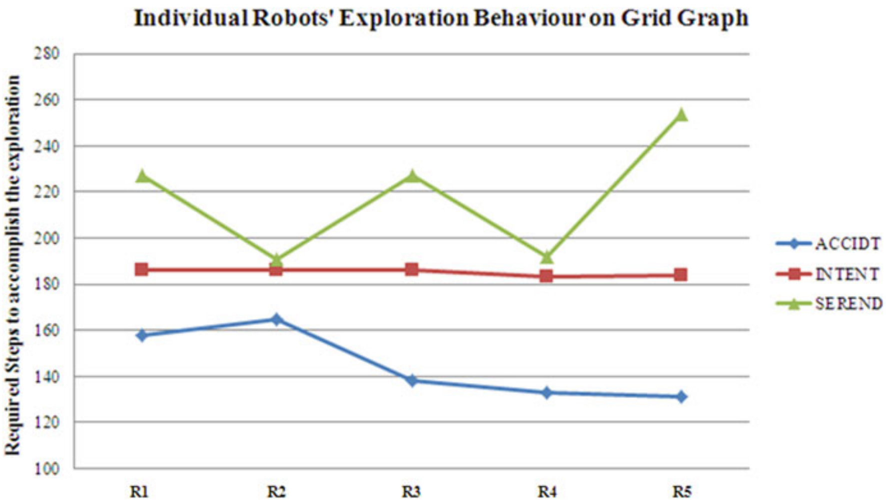


**Fig. 8** Individual robots' exploration behaviour on the grid graph

On the star topology, the robots of Accidental Rendezvous approach were faster because of the absence of the negative impact of Interruptibility. This impact affected the robots of both Intentional Rendezvous and Serendipity Rendezvous approaches.

Each individual robot within each team consumed the same amount of steps to explore the graph. The explanation of this behaviour comes from nature of the star graph. In such a graph, robots traverse each edge at minimum twice regardless of the selected frontier. Moreover, the given graph does not provide any shortcuts between

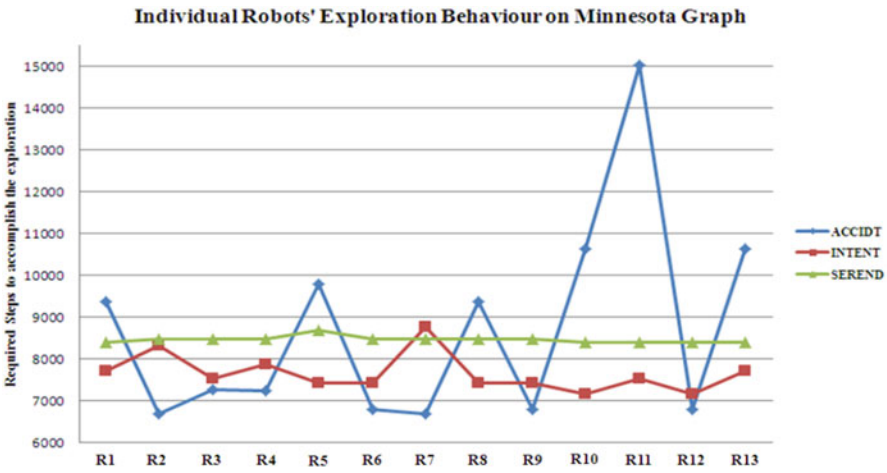


**Fig. 9** Individual robots' exploration behaviour on Minnesota graph

vertices. Hence, all robots of each approach have the same behaviour and consumed the same number of steps.

Based on the fact that finding shortcuts on the given star graph is impossible, the algorithm of Serendipity Rendezvous was not able to find any serendipity path. Therefore, the robots behaved in the same way as the robots of the Intentional Rendezvous approach.

Referring to the grid graph; the individual robots of each approach deviated in the required steps to accomplish the exploration. For instance, robots which selected a frontier that directed them inside the grid were faster to accomplish the exploration than the robots which selected circumference frontiers. This frontier classification is not applicable on the star graph; thus, it does not have an influence on breaking the similarity of the required steps among the team members.

The concept of Serendipity Rendezvous is constructed on seizing any chance of having a space of time between the two sequenced notifications on following the potential serendipity path. Intentional Rendezvous, on the other side, utilizes this time on exploration. R1 and R3 followed the serendipity path twice; however, without meeting other agents. Thus, they consumed extra steps. R5, in turn, carried it out four times; therefore, it consumed more steps than others. Even it estimated the path correctly twice; but, with minimum gaining margin. As a consequence, the robots of Serendipity Rendezvous approach showed the worst exploration behaviour comparing to other approaches.

On Minnesota graph, the team of Accidental Rendezvous showed the worst exploration performance comparing to other teams. The reason of this performance is because of the many scattered branches and shortcuts which Minnesota graph has. As a consequence, robots which only depend on Accidental Rendezvous have a lower chance to meet again accidentally after their separation because of the absence of scheduled rendezvous. R11 of Accidental Rendezvous approach is a good example of such an isolated robot. On the other side, the team which was affected by Interruptibility showed a sustainable exploration performance.

As a team, the robots of Serendipity Rendezvous were faster than the team of Intentional Rendezvous by 78 steps. The gain of steps may sound small, but could prove critical to search and rescue missions. This gain of steps is the result of mitigating the negative impact of Interruptibility.

As individuals, Serendipity Rendezvous approach shows a balanced utilization of robots on exploration comparing to Intentional Rendezvous. This enhancement is achieved by utilizing the time of the trip on meeting other robots which are not involved on the scheduled meeting. Thus, a larger number of robots shared the same knowledge and distributed themselves on the graph correspondingly. The average number of following the potential serendipity path correctly is 89.

## 5 Discussion and Conclusion

The algorithm of Serendipity Rendezvous depends on the ability to have several shortcuts to the rendezvous point. From these shortcuts, a serendipity path is drawn by depending on the reasoning result of Bayesian Networks. The variables of Bayesian Network are fed by statistical data which the robot gathered about its colleagues. Accordingly, two factors affect the performance of this algorithm: the existence of shortcuts in the given graph and gathering statistical data about robots. The existence of shortcuts is crucial to have a shorter path to the rendezvous point. Thus, a time space exists between the two sequenced notifications. This time is used to draw up the plan of the serendipity manoeuvre.

Referring to the star graph, Serendipity Rendezvous was deactivated by the involved robots because of the absence of shortcuts. Thus, the behaviour of Serendipity Rendezvous was the same as Intentional Rendezvous. The grid graph, on the other hand, provides many shortcuts. However, utilizing the available time for manoeuvre on continuing the exploration (i. e. Intentional Rendezvous) showed a better performance than following the serendipity path (i. e. Serendipity Rendezvous). The reason behind this poor performance of the Serendipity Rendezvous approach is because of the wrong decisions which the robots made about the potential serendipity paths. Therefore, robots consumed more steps to cross a path, which is larger than Interruptibility path, without meeting other robots on the path. To follow a serendipity path, robots reason on their partial statistical data which they gather from the periodic rendezvous sessions. Having more data about their colleagues, better decisions are made about the potential serendipity path. The experiments on Minnesota graph support this explanation where robots met their colleagues on the serendipity paths successfully.

In addition to mitigating the negative impact of Interruptibility, Serendipity Rendezvous provides a balanced utilization of robots on the exploration activities. Furthermore, attending a Serendipity Rendezvous does not affect the already scheduled rendezvous. Thus, this algorithm optimizes and encapsulates Intentional Rendezvous approaches.

To optimize the performance of the presented algorithm, robots have to decide on either following the serendipity path or continuing the exploration individually, once a manoeuvre is available. Such a trade-off is an example of future work.

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# Towards Benchmarking Cyber-Physical Systems in Factory Automation Scenarios

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**Abstract** A new trend in automation is to deploy so-called cyber-physical systems (CPS) which combine computation with physical processes. In future factory automation scenarios, mobile robots will play an important role to help customizing the production process, for instance, by transporting semi-products and raw materials to the machines. Therefore it will be important to compare the performance of mobile robots in such future logistics tasks. In this paper we sketch how the novel RoboCup Logistics League with its automated referee and overhead tracking system can be developed into a standard benchmark for logistics application in factory automation scenarios.

**Keywords** Cyber-Physical Systems · Automation · Production Technology · RoboCup

## 1 Introduction

A new trend in automation is to deploy so-called cyber-physical systems (CPS) to a larger extent. These systems combine computation with physical processes. They include embedded computers and networks which monitor and control the physical processes and have a wide range of applications in assisted living, advanced automotive systems, energy conservation, environmental and critical infrastructure control,

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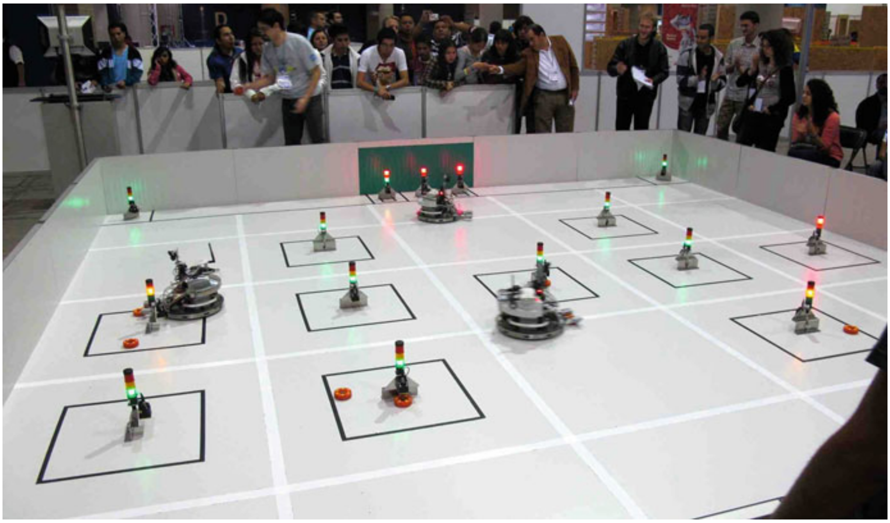

**Fig. 1** A LLSF competition during the RoboCup 2012 in Mexico City

or manufacturing [1]. In particular, mobile robots will be deployed for transportation tasks, where they have to get semi-finished products in place to be machined in time. In this new and emerging field, it will be very important to evaluate and compare the performances of robots in real-world scenarios. Hence, real-world benchmarks for logistics scenarios for CPS will be required. In [2], Dillmann mentions three essential aspects for a robot benchmark: (1) the robot needs to perform a real mission, (2) the benchmark is accepted in the field, and (3) the task has a precise definition. Furthermore, features such as repeatability, independency and unambiguity are required together with a performance metrics to measure the outcome of the task. This implies that ground-truth data are available in order to measure the performance objectively. In this paper we show that the novel RoboCup *Logistics League Sponsored By Festo* (LLSF) is well-suited for benchmarking logistics scenarios. The rest of this paper is organized as follows. In the next section we briefly overview the Logistics League and outline some interesting challenges of the league in Sect. 3. In Sect. 4 we show how the LLSF can become a benchmark test for logistic scenarios. Then we conclude.

## 2 The Logistics League Sponsored by Festo

In this section, we introduce the *Logistics League Sponsored by Festo* (LLSF) as a novel league under the roof of the RoboCup Federation. The objective of the LLSF is the following. Teams of robots have to transport semi-finished products from machine to machine in order to produce some final product according to some given production plan. Machines can break down, products may have inferior quality, additional important orders come in and need to be machined at a higher priority. For the LLSF, a team consisting of up to three robots starts in the game area of about 5.6 m $\times$ 5.6 m. A number of semi-finished products is represented by RFID-tagged *pucks*. Each is in a particular state, from raw material through intermediate steps to being a final product. The state cannot be read by the robot but must be tracked and communicated among the robots of a team. On the playing field are *machines*, RFID devices with a signal light indicating their processing status. When placed on a proper machine type, a puck changes its state according to the machine specification. The outcome and machine state is indicated by particular light signals. During the game a number of different semi-finished products need to be produced with ten machines on the playing field. Orders are posted to the robots requesting particular final products to be delivered to specific delivery gates and in specified time slots. All teams use the same robot base, a Festo Robotino which may be equipped with additional sensor devices and computing power, but only within certain limits (Fig. 1).

## 3 Challenges in the LLSF

The LLSF poses a number of very interesting AI and robotics research questions to be addressed ranging from planning algorithms for flexible supply chain optimization, path planning, dealing with incomplete information and noisy perception to multi-robot cooperation. The robots need to be autonomous, detect the pucks, detect and identify the light signals from the machines, know where they are and where to deliver the final product to. Basic robotics problems such as localization, navigation, collision avoidance, computer vision for the pucks and the light signals needs to be solved. Of course, all these modules have to be integrated into an overall robust software architecture. On top of that, the teams need to schedule their production plan. This opens the field to various concepts from full supply chain optimization approaches to simpler job market approaches. If the robots are able to prioritize the production of certain goods they can maximize the points they can achieve. In order to avoid resource conflicts (there can only be one robot at a machine at a time), to update other robots about the current states of machines and pucks, and to delegate (partial) jobs of the production process, inter-robot communication is required. There is a variety of complex scenarios that is captured by the LLSF which are important for evaluating the performance of logistics robots. Currently, only some tasks and command variables of the production process are taken into account. In the future, further tasks can be defined for evaluating different objectives such as efficient machine usage, throughput optimization, or energy efficient production. In the next section we outline how the LLSF can be developed into a benchmark for logistics scenarios before we conclude.

## 4 Developing the LLSF into a Benchmark

What features are required for the LLSF to become a benchmark for logistics scenarios for mobile robots? Following [2], features for a benchmark are: (1) the robot needs to perform a real mission; (2) the benchmark must be accepted in the field; (3) the task has a precise definition; (4) repeatability, independency, unambiguity of the test; (5) collection of ground-truth data.

The key question is what are the important aspects which a standard test must include. An important dimension for logistics scenarios for CPS are *supply chain optimization* (SCO) in an uncertain domain with failing machines and varying product qualities. Here, not only a single-robot scenario can be tested but also a multi-robot scenario can be benchmarked. The important aspect that can be tested is the *performance of the robot system* as such, e. g., how good are the path planning or collision avoidance capabilities of the robot while being deployed in a real task. The tasks can vary from different command variables such as *overall output of goods* or *operating grade of a machine*. In order to evaluate these aspects, we make use of an (semi-)automated referee system [3] which keeps track of the score that is achieved by the competitor and an overhead camera tracking system [4] (which is being tested at the moment) which provides ground-truth data of the positions of the robots and products (pucks) during the game. Additionally, the referee box keeps track of the machine states, so that the whole game can be reconstructed from the logged data. This allows for an unambiguous benchmark as each (automated) decision can be retraced. As the behavior of the machines can be programmed, each team could get the same machine setup. This ensures repeatability of the test. Some quantitative result of the supply chain optimization aspects such as throughput could fairly easily be judged by the score that a team achieves during a game. Other robotics tasks such as path planning or shortest paths metrics could be tracked with the overhead tracking system. An overall score could be established in comparison to a reference algorithm. The standard tests we are aiming at are to test capabilities of supply chain optimization in single- and multi-robot scenarios and integrated robotics tasks. The former can be tested by varying the command variables of the production process in different production scenarios, the latter can be tested with the provided ground-truth data. This way, parameters as effective path planning, collision avoidance and cooperative team behavior can be evaluated.

## 5 Conclusion

In this paper, we proposed the novel RoboCup Logistic League Sponsored by Festo as a robot competition benchmark for the emerging research field for cyber-physical system on the backdrop that logistic robots will become ever more important in future production scenarios. The LLSF is an interesting scenario for testing supply chain optimization algorithms where the production plan is carried out by robots in a real (mock-up) assembly line, either as a single-robot or even as a multi-robot problem. An interesting aspect is that the environment is uncertain, machines can fail, products can have inferior quality. Another source of uncertainty is the robot itself. The produced goods are carried around by real robots. This requires to deal with incomplete information, address noisy sensing, and build integrated logistic robot systems.

Besides the interesting aspects of logistics scenarios that are captured by the LLSF, for the LLSF an automated referee system (referee box) [3] and an overhead tracking system has been implemented. The referee box keeps track of all important events of the game, tracking the states of the machines during the game and points scored by a team. Together with the overhead robot trackingsystem, which has been adopted from a tracking system from RoboCup's Small-Size League [4], the referee box is also able to track the robots' and the products' positions during the game. This allows for a complete log-file of the match. With this information automated evaluations of games can be done allowing to compare different aspects of logistics scenarios. With these systems in place the LLSF has a high potential to develop into a standard testbed for logistics tasks.

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# CloudLogistic – A Formal Description of Exclusive Freight Routes Based on a Multi-Zone Model with Elliptic Isochrones

**Christian Tummel, Eckart Hauck and Sabina Jeschke**

**Abstract** Based on previous works this paper introduces a formal description of exclusive defined freight routes using a multi-zone approach to define source and target areas as elliptic isochrones. This work contributes to publications in context of the so-called “CloudLogistic” concept. As an innovative approach to strengthen the market position of Small and Medium-sized Enterprises (SME) and to increase their efficiency, the CloudLogistic concept aims for building a novel kind of freight cooperation in the area of Less than Truck Load (LTL) transports. The use of a multi-zone model enables the freight cooperation to maximize its efficiency, to implement innovative pricing strategies and to create individual unique selling features for each single Logistic Service Provider (LSP). By using an elliptic definition with geographical focal points for these zones a more flexible definition of source and target areas is realized. To reduce geographical impacts a time-based distance-function is used.

The presented design of the exclusiveness of freight routes by defining monopoles via so-called core-areas is a useful approach to deal between the individual requirements respectively intentions of each single LSP and the attainment of global goals of the whole collective network structure.

**Keywords** CloudLogistic · SME · LSP · Freight Routes · Exclusiveness · Elliptic Isochrones

## 1 Introduction

The Federal Ministry for Transport, Building and Urban Development (BMVBS) forecasts a substantial growth of the traffic volume in road haulage up to the year 2025 [1]. Especially the long-haul road transportation contributes to this trend. A growth of transport volume of about 55 % and an increase in traffic of about 84 % is expected. From the ecological and the economic point of view, these trends should not only be faced with an adjustment of the road network, but also with a more efficient

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use of the existing infrastructure [2]. In Germany, every fifth truck in commercial freight traffic is already driving without any load at all [3].

The so-called "CloudLogistic" concept addresses these challenges and represents an innovative concept for freight cooperation to strengthen the market position of Small and Medium-sized Enterprises (SME) in the long-haul road transportation. The concept transfers the strengths of already existing general cargo and Full Truck Load (FTL) networks to the area of Less than Truck Load (LTL) transports. Mentioned by Bretzke [4], CloudLogistic addresses the requirements for a promising, most likely successful cooperation model of a horizontal transport network for LTL. Bretzke aims for a fundamental decoupling from the customer. This means that all shipments have to be distributed centralized and globally optimized to the network LSPs – regardless of which LSP has given the job.

Usually it is not possible for a Small and Medium-sized Logistic Service Provider (LSP), to transport several LTL shipments together in one truck because there are not enough shipments within similar source and target areas. Hence, for a single LSP, several trucks are required for the transport of several LTL shipments. The CloudLogistic concept bundles LTL shipments of several cooperating LSP, via a cooperation network by combining corresponding LTL shipments to generate synergetic effects. Thereby, the concept relies on a line-based logistics model. The economic pressure [5] has risen due to the introduction of transporter tolls. This economic burden is noticed especially when dealing with LTL. Small and medium-sized LSP's have to cooperate with each other in order to fight against this strain [6].

Similar to the IT term "Cloud Computing", the "CloudLogistic" concept describes the ability and opportunity of the LSP's to share unused resources by participating in a freight cooperation network. This is done by using its infrastructure, its resources and scaling them locally while even sharing their own infrastructure and resources with the network. Several shipments of different network-partners will initially be bundled and assigned to previously established freight routes. Each route is operated by a partner of the cooperation. For a combined disposition of LTL shipments, freight routes are established, i. e. the relation between a source and a target area that is operated regularly by several trucks via point-to-point transportation [7].

With backing evidence from previous papers, this paper describes the spatial fundament of the CloudLogistic concept. This paper specifically addresses the formal description of the source and target areas of freight routes as elliptical isochronal multizone-areas and introduces the term of the core area and the exclusiveness of a freight route. After the brief introduction of the CloudLogistic concept in Paragraph 2, the formal model of the freight routes are precisely described in Paragraph 3. Subsequently, the exclusiveness of a freight route for a particular LSP will be introduced in Paragraph 4. In Paragraph 5, in connection with the conclusion, the motivation for future works is given.

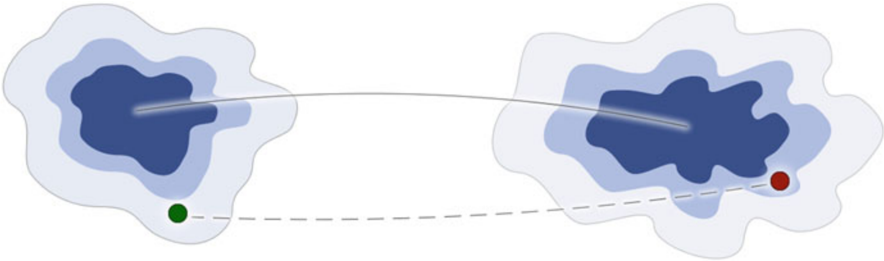

**Fig. 1** Source and target area of a freight route and its main leg

## 2 An Elliptic Multizone-Model

The foundation for the formal description of freight routes is the formal description of their implied source and target areas. Shipments whose origins are within the source area of a freight route and if the destination is in its target area, the shipment can be sent off in the corresponding direct transport (see Fig. 1).

Source and target areas are consequently bordered within a specific geographical space. This space is individually set depending on the freight route. In order to reach the necessary national wide coverage and to create optimization potentials which exceed the immanent usage of synergies, it is necessary to create possibilities for the overlapping of source and target areas within different freight routes. The corresponding optimization problem was subject of earlier work [8].

The cooperation which is considered as the superordinate entity, strives for maximum national coverage and optimization potentials for the collective. Contrary to this, the individual LSP's strive for its own personal interests. Consideration in describing the freight routes is necessary, especially when reaching a unique selling point in the form of exclusive operations of different freight regions and its source and target areas (see Paragraph 4).

In order to define the terms source area respectively target area and finally freight route, the term of the geocoordinate is introduced. The definition is according to previous works [8, 9].

**Definition 1 (geographic location/set of all geographic locations)**
*Let* $\lambda \in \mathbb{R}$ *be the longitude* $-180 \leq \lambda \leq 180$ *and* $\phi \in \mathbb{R}$ *the latitude* $-90 \leq \phi \leq 90$ *then the ordered pair* $A = (\lambda, \phi)$ *is called* geographic location. *Let* $\mathbb{W}$ *denote the* set of all geographic locations.

The source area of a freight route is defined via multiple zones and via two spatial geographic locations; A and B (see Fig. 2). The geographic location A represents the geographical location of the depot respectively LSP and declares a surrounding area. With geocoordinate B the area can be optionally spanned and adjusted.

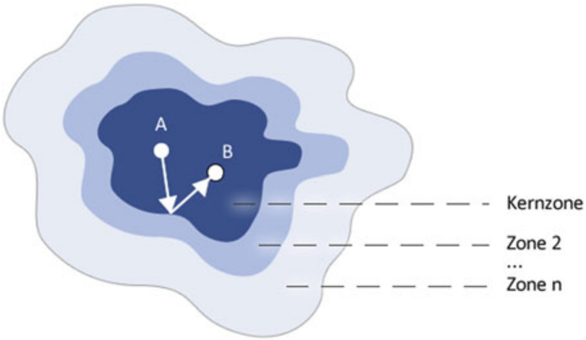


**Fig. 2** General scheme of area as elliptical multi-zone model

Choosing a geographic location B is done in consideration of the specific geographic characteristics of a particular depot and in accordance with the LSP.

A source area is not only defined through its core-area but also through multiple expansion zones. In particular the individual freight charge and the probability of the shipment being sent on a particular freight route are based on such zones. LSP are compensated higher when the freight is shipped to a farther zone. It is also the goal of the cooperation to allow a most ecological assignment of the cargo on a particular freight route, while meeting the economic variables, from the perspective of the superordinate simultaneously. Therefore, the allocation of a shipment to a particular freight route is more probable when origin and destination of a shipment are in or nearby a core area.

For the foundation for the description of such zones, a time-based approach was chosen which considered the available road networks. In order to estimate the relevant distances a truck-based routing planer is used. These should be able to calculate the distances for geographic locations which are not directly part of the road network and otherwise would have to be estimated.

According to Definition 1, the general underlying distance function will be introduced considering the metric triangle inequality. Specifically the distance function in the CloudLogistic concept takes shape as a time-based distance function, considering the road network. Hence the set of two geographic locations; A, B is assigned to the time value which requires a truck to drive from A to B using the road network.

**Definition 2 (geographic location/set of all geographic locations)**
*A funktion* $d: \mathbb{W} \times \mathbb{W} \rightarrow \mathbb{R}$ *is called* distance function*, if for any geographic locations* $A \neq B \neq C \neq W$ *the following conditions hold:*

$d(A, B) \geq 0$ *(The distance is always positive)*

$d(A, B) = \Longleftrightarrow A = B$ *(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 must not decrease the distance)*

Using Definition 2, the formal description of source and target areas will be introduced as an abstract area description. First the general area without zone division is defined. The definition is based on the "Pins-and-String Method" (Gardner's Ellipse) [10] which describes elliptical geometries.

**Definition 3 ((source- and target-) area/focal points)**
*Let A, B* $\in \mathbb{W}$ *be two geographic locations,* $\bar{r} \in \mathbb{R}$ *a real number and d:* $\mathbb{W} \times \mathbb{W} \rightarrow \mathbb{R}$ *a distance function. Then the set:*

$$G_{A,B,\bar{r},d} = \{X \in \mathbb{W} | d(A, X) + d(X, B) \leq \bar{r}\} \subset \mathbb{W}$$

*is called area. In this case A, B are called focal points of this area.*

If the time-based distance function $d_t$ is chosen, the geographical area $G_{A,B,\bar{r},d_t}$ is defined as an elliptical isochrone. The definition above will now be extended into the already motivated multi-zone approach.

**Definition 4 (multi-zone area/set of all areas)**
*Let* $G_{A,B,\bar{r},d}$ *be an area. Further let* $Z = \{z_1, z_2, \ldots, z_n\} \subset \mathbb{R}$ *be a set of different distances with* $0 < z_1 < z_2 < \cdots < z_n = \bar{r}$ *and n > 1. Then the set* $G_{A,B,\bar{r},d,z}$ *is called multi-zone area and* $\mathbb{G}$ *denotes the set of all areas.*

If location B of a source area is not given, all locations are within one zone which can be reached within a maximum time-frame from the depot A. The needed time to collect the shipment at its origin – basically the route from depot to origin and back again – is in this case limited to 40 min. By specifying location B the area will be adjusted in an elliptic way. Such kind of area describes all geographic locations which are part of a turn from A to B (including the detour). This turn is limited to a time-frame of 40 min. The target area of a freight route is defined analogically.

Geographically speaking, the shape of a defined area significantly varies with the choice of a specific distance function. The choice of the Euclidean distance of two graphical locations describes a completely different geographical area as if the choice were – like in the case of the CloudLogistic concept – a time-based distance function. The choice of source area and target area is defined in connection with the acquirement of a so-called freight concession. This decision would of course be reached in coordination with the cooperation. The variables A, B and their respective zones are assigned to individual source and target areas. As seen as part of the model, many time-zones can be indicated.

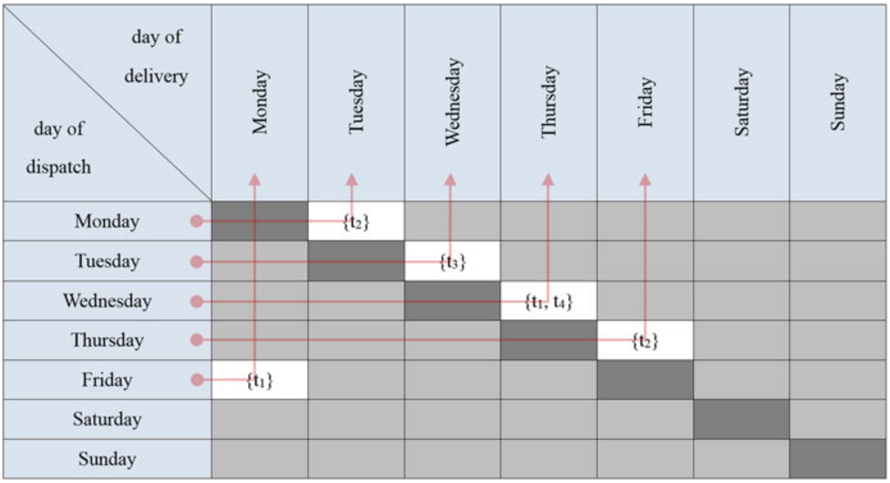


**Fig. 3** Example of a schedule of a freight rout with day of dispatch, day of delivery and the specific resources $\{t_1, t_2, t_3, t_4\}$.

## 3 A Freight Route with its Schedule

Before introducing the term freight route formally, the terms resource and schedule has to be defined first. In this model only the truck on an LSP is taken into account for defining the resource. As the LSP only is responsible for providing the needed human resources, the consideration especially of the truck driver is not part of this model. The given schedule with its related resources is implying the human resources sufficiently. The schedule describes in the form of a timetable the day of dispatch, the day of delivery and the specific resources, which are provided to serve the related source and target areas (see Fig. 3).

The given example describes the schedule of a freight route of an LSP which serves a relation between a source and a target area from Monday to Tuesday, from Wednesday to Thursday, from Thursday to Friday and from Friday to Monday with only one truck. The main leg from Tuesday to Wednesday is served by an additional truck.

The following definition is not restricted to a period of a week, but it is based on the specific working days.

**Definition 5 (trucks/schedule of a freight route/resource)**
*Let* $\mathbb{T}$ *be the set of all* trucks *of a LSP. Furthermore let* $\mathbb{D}$ *be the set of all working days,* $i \in \mathbb{D}$ *the day of dispatch and* $j \in \mathbb{D}$ *the day of delivery.*
*Then* $f$ *denotes the* schedule of a freight route *with:*

$$f : \mathbb{D} \times \mathbb{D} \to Pot(\mathbb{T}), (i, j) \mapsto T$$

*as map from the pair* $i \in \mathbb{D}$ *(day of dispatch) and* $j \in \mathbb{D}$ *(day of delivery) in a set of trucks* $T \in Pot(\mathbb{T})$*. Then each truck* $t \in T$ *is called* resource *for day of dispatch i to day of delivery j.*

At this moment a more detailed definition is not needed. It is sufficient to say that resources of freight routes (so the implied trucks) are specified with a lot of different characteristics (i. e. the available loading meter, the payload limit, lifting platform, COIL-device). Which parameters are needed depends on the specific application and the optimization case.

Based on the definitions above, now the freight route has to be formally defined as the union of source and target areas, its implied main leg and the resources which has been allocated in the schedule.

If the shipments origin is part of a freight routes source area and its destination is part of the corresponding target area, the shipment will be assigned to this freight route (see Fig. 1). If there is more than one fitting freight route, the decision depends on several factors (i. e. fairness factors, economic aspects) which are needed to reach the specific optimization goals. For more information the reader may refer to earlier works [9].

**Definition 6 (freight route/set of all freight routes/core-area)**
*Let* $G^s \in \mathbb{G}$ *be a source area and* $G^t \in \mathbb{G}$ *be a target area. Furthermore let f be a schedule of trucks* $\mathbb{T}$ *of an LSP. Then the tuple* $l = \langle G^s, G^t, f \rangle$ *is called* freight route *and* $\mathbb{L}$ *denotes the* set of all freight routes.
*Then the area* $G_{A,B,z_1,d,\{z_1\}} \subset G_{A,B,\bar{r},d\{z_1,z_2,\ldots,z_n\}} = G^s$ *is called* source core-area of freight route l *and the area* $G_{C,D,z_1,d,\{z_{1'}\}} \subset G_{C,D,\bar{r}',d,\{z_{1'},z_{2'},\ldots,z_{n'}\}} = G^t$ target core-area of freight route l.

## 4 Exclusive Freight Routes

By acquiring a so-called freight route concession the concessionaire obtains special rights to serve the defined source and the target areas exclusively. These exclusive rights are specified by the terms source area monopoly and target area monopoly (see Figs. 4 and 5).

The specific source core-areas of two different freight routes may overlap each other, if the related target core-areas do not overlap each other (source area monopoly). The specific target core-areas of two different freight routes may overlap each other, if the related source core-areas do not overlap each other (target area monopoly).

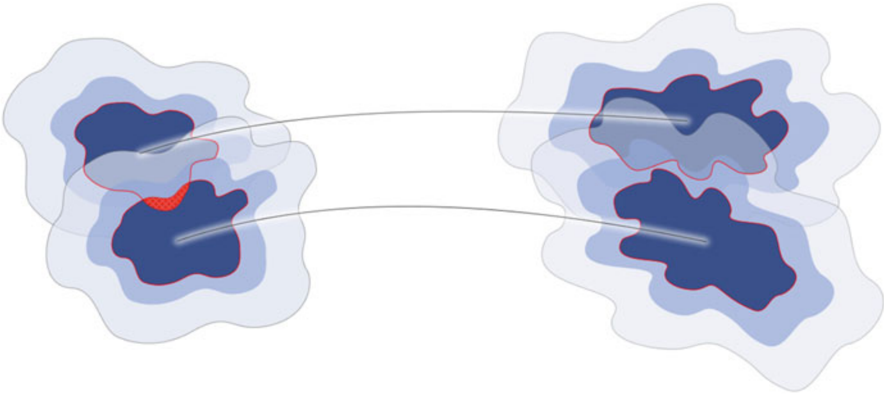

**Fig. 4** Example of a valid concession contracting by observing the source area monopoly

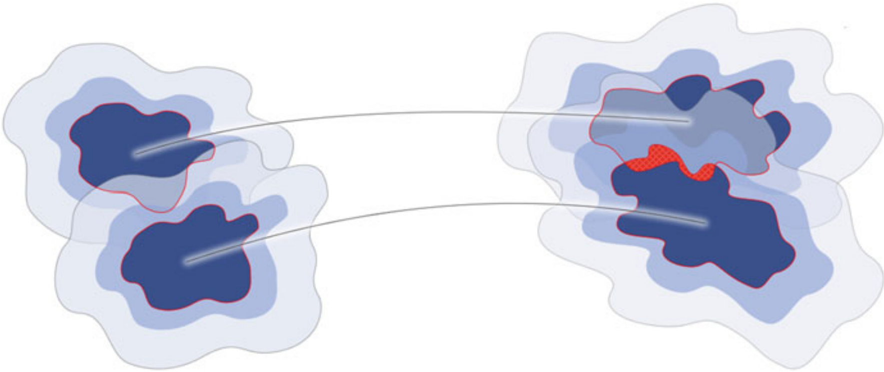

**Fig. 5** Example of a valid concession contracting by observing the target area monopoly

In this context a freight route is called exclusive, if on the one hand the source area monopoly and on the other hand the target area monopoly constraints hold. This means after a freight route concession is granted, the core-areas of later acquired freight routes may not overlap both core-areas of the existing freight route concession. A formally description of source and target area monopoly and the exclusiveness of a freight router is given in Definition 7.

**Definition 7 (source & target area monopoly/exclusiveness of a freight route)**
*Let $G_l^s \in \mathbb{G}$ be the source area and let $G_l^t \in \mathbb{G}$ be the target area of a freight route $l \in L$. Furthermore let $G_l^{sc} \subset G_l^s$ be the source core-area and $G_l^{tc} \subset G_l^t$ the target core-area of $l$.*

*For l a* source area monopoly *is given if:*
$\nexists x \in L$ *with* $\mathrm{l} \neq \mathrm{x}$ *with source core-area* $G_x^{sc}$ *with* $G_x^{tc} \cap G_l^{tc} \neq \emptyset$.
*Analogous a* target area monopoly *is given if*:
$\nexists x \in L$ *with* $l \neq x$ *with target core-area* $G_x^{tc}$ *with* $G_x^{tc} \cap G_l^{tc} \neq \emptyset$.
*A freight route l will be denoted as* exclusive, *if:* $\nexists x \in L$ *with* $l \neq x$ *with source core-area* $G_x^{sc}$ *and target core area* $G_x^{tc}$ *with* $G_x^{sc} \cap G_l^{sc} \neq \emptyset \wedge G_x^{tc} \cap G_l^{tc} \neq \emptyset$.

On the one hand this definition observes the requirements of the LSPs to establish individual exclusive territories and the related territorial unique selling feature for each LSP. To reach the needed domestic coverage and to create potentials to optimize the global assignment scenario by aiming different optimization goals for the collective, the exclusiveness of a freight route is restricted to the specific core-areas on the other hand. The contracting of such kind of concessions has to observe these given guidelines. Nevertheless for reaching a high domestic coverage the contracting is not able to guarantee the observance of this guideline. Therefore the following extension is given: In case of competing the earlier contracted freight route will be favored.

## 5 Conclusion and Outlook

The presented formal model forms the basis for the development of the related centralized software-based service, which is needed to realize the CloudLogistic concept. On the one hand the introduced multi-zone model with elliptic isochrones combines the requirements of medium-sized LSPs to a time-based description of source and target areas with the opportunity to adjust them geographically by choosing two focal points. On the other hand creating overlapping areas enables the chance to reach a domestic coverage and it creates potentials to optimize globally by aiming for goals which improve the collective. Respecting the requests of the LSP to create an individual unique selling the exclusiveness of a freight route according to their specific core-areas has been integrated in the model description.

Furthermore the presented model is the base of the related pricing model, which is geared to the multi-zone description of freight routes. Also the related optimization process uses this definition to minimize the distances between origins and source core-areas respectively destinations and target core-areas by choosing the specific freight route. Based on this model the further work aims for the development of a problem-specific optimization procedure and the evaluation of the operative assignment planning. Further methods for optimizing the whole network from a strategically and tactical point of view is supposed.

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# CloudLogistic – Line-Based Optimization for the Disposition of LTL Shipments

**Christian Tummel, Christian Franzen, Phil Friedrichsmeier, Nadine Voßen, Philipp Wolters, Eckart Hauck and Sabina Jeschke**

**Abstract** As a real application of the in Tummel et al. (The Multi-Depot Heterogeneous Fleet Vehicle Routing Problem With Time Windows And Assignment Restrictions (m-VRPTWAR), 2011) introduced problem class m-VRPTWAR – the "multi-depot heterogeneous fleet vehicle routing problem with time windows and assignment restrictions" - this paper will introduce the so-called "CloudLogistic" concept. The problem addresses the assignment of a set of shipments to a set of freight routes in order to minimize unused cargo volume of the vehicles. The assignment of each shipment is restricted to a subset of freight routes. Furthermore, the shipment has to be delivered in a specific time window. Therefore, it is necessary to determine an order of shipments for each freight route that guarantees the observance of all time windows. The problem class m-VRPTWAR abstracts the implied optimization problem. Besides the introduction of the "CloudLogistic" concept, the main requirements for the software-based shipment processing are discussed, which is the central part of a software-based solution for an implied freight cooperation of Less Than Truckload (LTL) shipments. For the evaluation of problem-specific solvers, as well as for an improved evaluation of the feasibility of the m-VRPTWAR, realistic test data come into place according to Tummel et al. (An Incremental Online Heuristic for Evaluating the Feasibility of the m-VRPTWAR, 2011). Besides a detailed description of the concept a method for the generation of realistic test data will be presented. Finally the evaluation of a Repacking First Fit approach (RFF) as a solution for the discussed feasibility check will be extended by considering different choices of repacking depths.

**Keywords** Vehicle Routing · Freight Cooperation · SME · Cooperation Model · Logistic Model · LTL Shipments · Line-Based Optimization

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## 1 Introduction

In its recent study for traffic linkages in Germany the Federal Ministry for Transport, Building and Urban Development (BMVBS) forecasts a substantial growth of the traffic volume in road haulage up to the year 2025 [1]. Especially the long-haul road transportation contributes to this trend. A growth of transport volume of about 55 % and an increase in traffic of about 84 % is expected. From the ecological and the economic point of view, these trends should not only be faced with an adjustment of the road network, but also with a more efficient use of the existing infrastructure [2]. In Germany, every fifth truck in commercial freight traffic is already driving without any load at all [3].

The Project "CloudLogistic" – funded by the state North Rhine-Westphalia of the Federal Republic of Germany and by means of the European Regional Development Fund (ERDF) – addresses these challenges. "CloudLogistic" focuses its research on a more innovative logistics concept for freight cooperation to strengthen the market position of Small and Medium-sized Enterprises (SME). In this concept the strengths of already existing general cargo and Full Truck Load (FTL) networks are transferred to the area of Less than Truck Load (LTL) transports.

Usually it is not possible for a Small and Medium-sized Logistic Service Provider (LSP), to transport several LTL shipments together in one truck because there are not enough shipments within similar source and target areas. Hence, for a single LSP, several trucks are required for the transport of several LTL shipments. The basic idea of "CloudLogistic" is to bundle LTL shipments of several cooperating LSP's, via a cooperation network, by combining corresponding LTL shipments to generate synergetic effects. Therefore, the "CloudLogistic" concept relies on a line-based logistics model.

The addressed problem deals with the assignment of a set of shipments to a set of freight routes in order to minimize unused cargo volume of the vehicles. The assignment of each shipment is restricted to a subset of freight routes. Furthermore, the shipment has to be delivered in a specific time window. Thus, it is necessary to determine an order of shipments for each freight route that guarantees the observance of all time windows.

## 2 Related Work

The described problem of shipment assignment corresponds with the problem [4] that is worked out as a mathematical model in the form of an Integer Linear Program (ILP). Analogues to the literature taxonomy this problem was classified as "Multi-Depot Heterogeneous Fleet Vehicle Routing Problem with Time Windows and Assignment Restrictions" (m-VRPTWAR). Paper [5] has established a heuristic for the implied evaluation of the feasibility of the m-VRPTWAR based on [4].

Since [6] first addressed the issue of vehicle routing problems, the subject has become an area of intensive research in logistics. In [7] a multilevel solution method

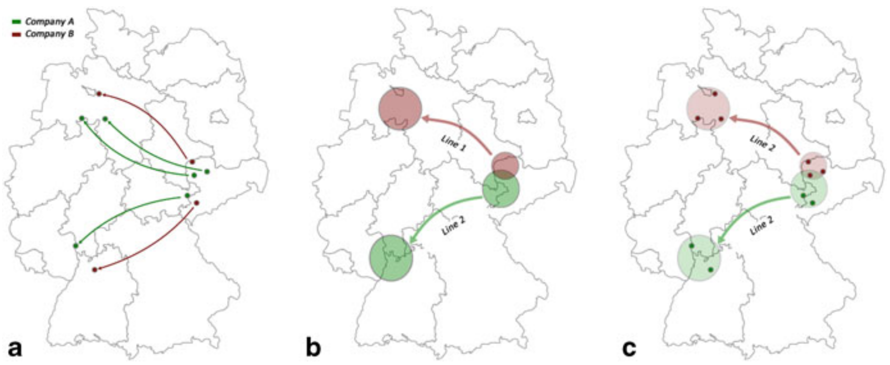


**Fig. 1** Visualization of the "CloudLogistic-Concept"

has been shown for the "Multi-Depot Heterogeneous Fleet Vehicle Routing Problem with Time Windows". First the algorithm determines reasonable clusters of nodes with the help of a heuristic approach. Afterwards, it distributes these nodes over the trucks in a valid order by solving a Mixed Integer Linear Program (MILP). The same problem class was covered by [8]. This work didn't focus on the development of a solution method, but the development of an efficient mathematical formulation of the problem model. Considering the more general problem class of the "Vehicle Routing Problem with Time Windows", the papers of [9–11] may be referred to.

## 3 The Cloudlogistic-Concept

Similar to the IT term "Cloud Computing", the "CloudLogistic" concept describes the ability and opportunity of the LSP's to share unused resources by participating in a freight cooperation network. This is done by using its infrastructure, its resources and scaling them locally while even sharing their own infrastructure and resources with the network. The basic principle is visualized in Fig. 1. Several shipments of different network-partners will initially be bundled and assigned to previously established freight routes (A). Each route is operated by a partner of the cooperation. For a combined disposition of LTL shipments, freight routes are established, i. e. the relation between a source and a target area that is operated regularly by several trucks via point-to-point transportation (B). The trucks are provided by the cooperating partners. Shipments will be collected in the source area of the route and then carried without any turnover directly to the corresponding target area, where they are locally distributed (C).

The basic aim of the "CloudLogistic" concept is to determine an assignment of shipments to a certain set of freight routes while decreasing the number of needed trucks, respectively the needed FTL capacity. Other goals like the minimization of the distance in the target area, the minimization of the total cost or a multi-criterian

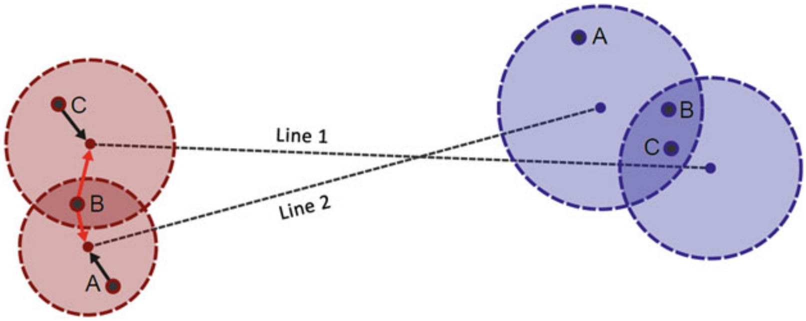


**Fig. 2** Visualization of the assignment problem

goal could also be implemented. The CloudLogistic-approach initially assumes – based on the investigations of [3] – that the ecological and the economic benefits of the overall optimization potential is maximized if the minimization of the needed FTL capacity is chosen as the main optimization goal. The assignment of shipments to a set of certain freight routes is classified as a NP-hard optimization problem [4]. The problem is illustrated in Fig. 2.

First, shipment A is pushed into the system – which can only be assigned to freight route 2. In contrast, both routes are feasible for the transportation of shipment B. If shipment B is assigned to freight route 1 and freight route 2 does not have sufficient unused capacity, shipment C may not be delivered because C can only be assigned to freight route 2. The number of such collisions increases, if the source and target areas of multiple freight routes overlap and additionally a large number of corresponding shipments have to be distributed.

## 4 Requirements for the Shipment Processing

The "CloudLogistic" concept represents a novel freight cooperation model. To realize this concept the creation of software-based centralized solutions which fulfil the requirements of the inducted business processes is needed. One of the main processes, which have yet to be investigated, is the processing step for new shipments pushed into such a kind of system. In this section the main requirements for shipment processing are discussed.

As explained above, the formation of freight cooperation is intended – in contrast to common freight exchanges. Therefore, the shipment processing has to ensure that all accepted shipments can and will be delivered and consequently, can be allocated to a certain freight route. Otherwise, the shipment will be rejected. This essential requirement has far-reaching consequences for the design of the architecture, the construction of the needed software-based platform and used optimization techniques. If there is not enough capacity to deliver all shipments or the assignment always fails because there occur other conflicts like violation of the defined time windows,

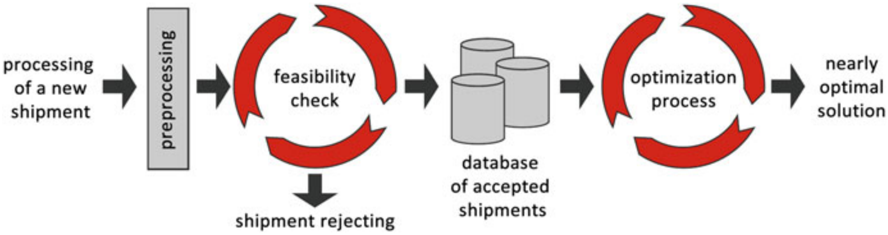


**Fig. 3** Overview of the fundamental IT-based shipment processing steps

no assignment can be found. The existence of such a situation has to be prevented. Therefore, the existence of a fitting assignment has to be ensured to make sure that all shipments can and will be delivered.

For this purpose the shipment processing has to be split into two components, as shown in Fig. 3. The first component represents the evaluation of the feasibility that incrementally checks if a new shipment can additionally be assigned to a certain freight route. It has to be ensured that an allocation that fits all restrictions for each shipment and freight route always exists. If no assignment can be determined, then the shipment may not be accepted by the freight cooperation. On the other hand a component is needed, which represents the final optimization step. This step has to calculate the optimal allocation of shipments to corresponding freight routes under the defined restrictions.

In the following part some basic requirements for both introduced components are described. Firstly the requirements for the final optimization techniques are addressed. Then they will be supplemented by additional requirements for the preprocessing phase and the evaluation of the feasibility. These requirements have to be taken in to account for developing the platform. The requirements are summarized in Table 1. In addition to the requirement analysis the use of realistic test data is essential to evaluate different implementations of the whole shipment processing step. In the following a method for the generation of realistic test data will be introduced.

## *4.1 Capacity-Based Constraints*

In addition to the formulated optimization target, there are several restrictions which have to be considered by the optimization. One of these restrictions is given by the total capacity of the freight routes. The capacity of a truck is defined by the maximum load weight and the corresponding number of loading meters. The considerations of driving and rest times of the truck drivers, as well as the observance of pick-up time windows, do not matter for the main optimization problem at this time.

**Table 1** Requirements for the multilevel shipment processing

| Requirements concerning the "optimization process" | |
|---|---|
| Capacity-based constraints | The total weight and the amount of loading meters may not be exceeded for each truck |
| Time window-based constraints | By observing all delivery time windows, sequences for delivering of allocated shipments have to be identified for each freight route |
| Routing-based constraints | A shipment may only be allocated to the permitted freight routes |
| Additional assignment constraints | Additional assignment restrictions have to be addable |
| Optimization step time constraint | The main optimization step must not take more than 1.5 h to estimate a "good" allocation |
| *Requirements concerning the "feasibility check"* | |
| Feasibility check time constraint | At least 50 shipments per minute have to be tested |
| *Requirements concerning the "pre-processing"* | |
| Pre-processing time constraint | Shipment data of at least 50 shipments per minute must be processed in the pre-processing step |

## *4.2 Time Window-Based Constraints*

In contrast, it has to be ensured that the delivery time window is accurate. Therefore the optimization step has to calculate a possible delivery sequence for each freight route in which the shipments are deliverable. The delivery sequence has to consider unexpected delays, like traffic jams or delays while unloading in terms of appropriate temporal buffers.

## *4.3 Routing-Based Constraints*

A further requirement addresses a special property of the introduced logistic model which is denoted in the following as an assignment restriction (according to [12]). For each shipment a set of freight routes which is able to handle the assigned shipments is defined. Therefore a shipment cannot be assigned to all available freight routes. An obvious allocation constraint is created by the source and target areas of the freight route. A shipment can only be assigned to routes, where source and target areas cover the pickup coordinates and the destination of the shipment.

### *4.4 Additional Assignment Constraints*

Restrictions concerning certain shipment types respectively some categories of goods (i. e. dangerous goods) also need to be taken into consideration. Additionally, different optimization goals lead to a combined multicriterian definition. Especially the use of a fairness model, which prefers or punishes certain LSP's, the goals of the national economy, the goals of the LSP's and the goals of the freight cooperation as an independent company are competing against each other. The possibility of an expansion and adaption of the optimization process considering such constraints has to be taken into account.

### *4.5 Optimization Step Time Constraint*

There are some given performance requirements for the optimization process. The calculation of an optimal allocation of shipments to freight routes has to be completed within a period of 1.5 h on a defined test system. A longer time for the processing step is not acceptable to ensure a frictionless integration into the running business processes of the LSP's.

### *4.6 Feasibility Check Time Constraint*

The requirements presented up to this point, except the non-functional requirement R5, are also requirements for the processing step of the feasibility evaluation. For this step, more restrictive performance requirements have to be met. The feasibility check has to be able to handle shipments requests as quickly as possible, so that waiting periods for the LSP's not arise. The notice for acceptance or rejection of a shipment has to occur within seconds. Since there is no reliable history data about the frequency of receiving shipments of LTL cooperation networks, the order of an existing general cargo network of an average business day shall be used as an indicator (Fig. 4). Accordingly, the feasibility check has to process 50 shipments per minute at maximum.

### *4.7 Pre-Processing Time Constraint*

The pre-processing step shown in Fig. 3 is needed to determine the geographical coordinates of the shipments origin and its destination. Additionally, it has to be determined which freight routes are suitable to deliver the shipment under consideration of all known restrictions. In this case, a lot of temporal distances have to be determined using a software-based routing planner. Naive approaches would produce

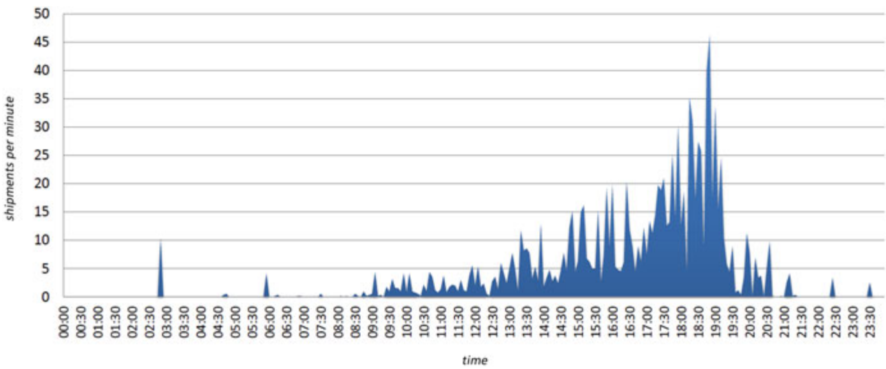


**Fig. 4** Orders of a general cargo freight cooperation

thousands of unnecessary distance requests. This would hurt temporal constraints given here. A time line of a few seconds must be observed, for example, by using appropriate index structures to significantly reduce the number of distance requests.

In addition to the requirement analysis the use of realistic test data is essential to evaluate different implementations of the whole shipment processing step. In the following a method for the generation of realistic test scenarios will be introduced.

## 5 Test-Data Generation

In context to the introduced "CloudLogistic" concept and to the evaluation of solutions for its implied optimization and feasibility problems, the use of realistic test data is essential. So, a set of test data shall illustrate a nearly realistic compilation of freight routes and shipments. Besides the generation of realistic test data, it is also conceivable using different (and sometimes unrealistic) worst-case-scenarios for the tests to evaluate a solution method even in such extreme cases. To give an example, the allocation limit for all shipments could be eliminated. This would dramatically increase the possible combinations of shipment and freight routes and it would be difficult to evaluate the applicability of the solution method for treating this problem. Instead, the applicability of an algorithm for solving a general optimization problem of the class m-VRPTWAR would be evaluated. The following assumptions are the results of requirement workshops with experts in logistics and different experts of local LSP's.

It is reasonable to choose the distribution of companies across Germany as an indicator for the distribution of realistic source and target areas. It also is reasonable to generate shipments corresponding to these areas. For the freight routes themselves a realistic extension of the area is assumed. For simplification source and target areas are defined as Euclidean circles. For the generation of test data the Euclidean model holds and is easily changeable to other approaches. Here a source area with an

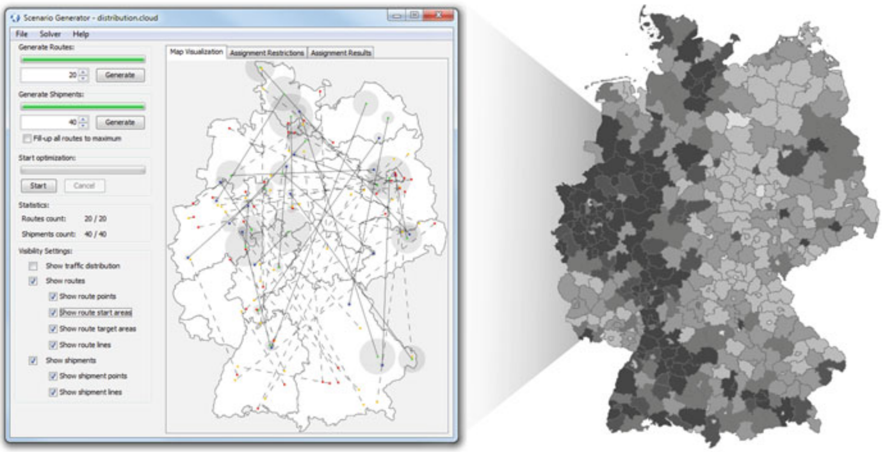


**Fig. 5** Screenshot of the developed tool for test data generation

extension of 5– km and for the target area an extension of 10–50 km is considered to be realistic. For a single shipment all other parameter besides the source and target location are needed. Those are the number of needed loading metres, the weight and the time period for unloading. In our definition a LTL shipment usually consist of 7–27 pallets. For each pallet 0.4 loading meters as well as a random weight of 100–800 km is valid. For unloading a time period of 1–2 min for each pallet is considered. The time window for the delivery is chosen randomly between 8:00 a.m. and 6:00 p.m.

For the generation of test scenarios a tool has been developed. It realizes a projection of the distribution of German companies (Fig. 5) to a probability distribution. For densely populated regions (in the map shown as dark regions) a higher probability is assumed. For sparsely populated regions (in the map shown as bright regions) a lower probability is chosen. Using the presented tool (based on the shown probability distribution) randomized coordinates will be chosen and used as center of the source and target areas. Figure 5 shows a screenshot of the developed tool and an example of generated source and target areas as certain freight routes as well as the source and target locations of several shipments.

In order to evaluate the goodness of the feasibility check the number of shipments which are rejected incorrectly has to be identified. If a shipment is generated as described previously and if this shipment is refused by the feasibility check, we don't know whether it was rejected because it could not be scheduled or whether the feasibility check didn't found the matching assignment. Therefore it has to be ensured that all shipments of a test case can be scheduled. Then a useful evaluation of the feasibility check is possible. In addition the behaviour of a solution method shall be investigated, in case the available trucks are already reaching their capacity limits.

So, to evaluate a solution which represents the feasibility check the generation of shipments has to be changed slightly. First a number of freight routes are generated according to the assumptions above. In a second step shipments are created by dividing the available capacity of the freight routes in certain pieces according to the restrictions and assumptions we made for the shipment properties. Then for each piece a source and a target location within the source area respectively the target area of the freight route is randomly selected. For the generation of realistic and practicable delivery time windows the time span of 8 a.m. to 6 p.m. will be divided into intervals of equal size according to the partition of the freight capacity. The delivery time windows for each shipment now are generated by a randomized deviation around the intervals central point. This approach ensures that all shipments can be scheduled within its spatial and temporal requirements and there are enough shipments for reaching the capacity limit of all freight routes. Moreover, such kind of scenario can be assumed as realistic.

## 6 Evaluation of the Feasibility-Check

In addition to the in [5] presented Repacking First Fit algorithm (called RFF) as a first implementation of a feasibility check, based on the here introduced generation of test data a scenario with 3500 freight routes and 14495 shipments was used to additionally evaluate different repacking depths. The RFF algorithm first tries to find a freight route to which the shipment can be assigned, using a first fit approach. 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. On the one hand this approach is supposed to make room for the new shipment; on the other hand it ensures that as the cargo volume of the freight routes is utilized as much as possible.

A more detailed description of the algorithms is presented in [5]. Figures 6 and 7 show the results of the evaluation of the RFF algorithm for eight different repacking depths and for a scenario without any repacking step.

As presented in Fig. 6 the use of a repacking approach significantly reduce the ratio of rejected shipments. By scaling up the repacking depth the ratio of rejected shipment decreases logarithmical. Corresponding to the rejection rate in Fig. 7 the required execution time is shown in order to check all shipments in terms of ability to deliver. Here by scaling up the repacking depth the derivation of each function increases exponentially resulting in increasing execution time for a single shipment. Considering Fig. 7 with a repacking depth of 6 the execution time raises up to 37.9 ms. So a violation of the introduced *feasibility check time constraint* – "At least 50 shipments per minute have to be tested" – is not given. In this case the rejection rate in the given scenario decreases down to 7.77 %. The choice of a higher repacking depth leads to a marginal decrease of this ratio. For reaching an optimal result the repacking depth can be chosen dynamically with respect to the current number of requests.

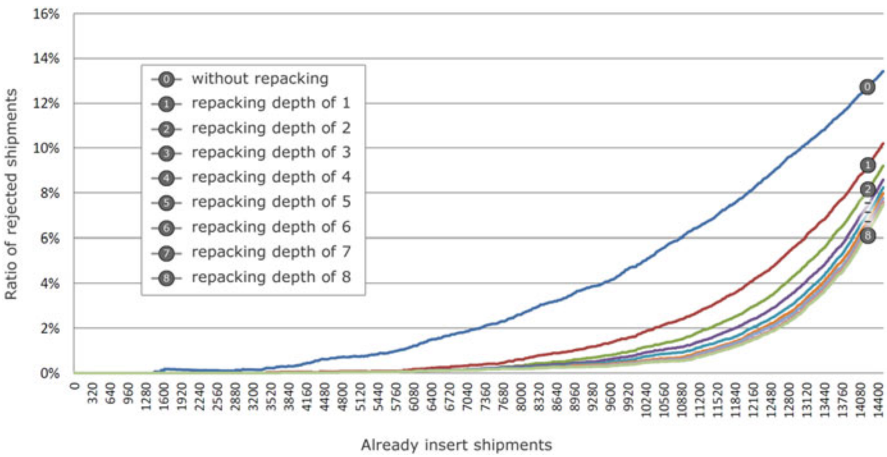


**Fig. 6** Rejection rate of the RFF algorithms for using different repacking depths

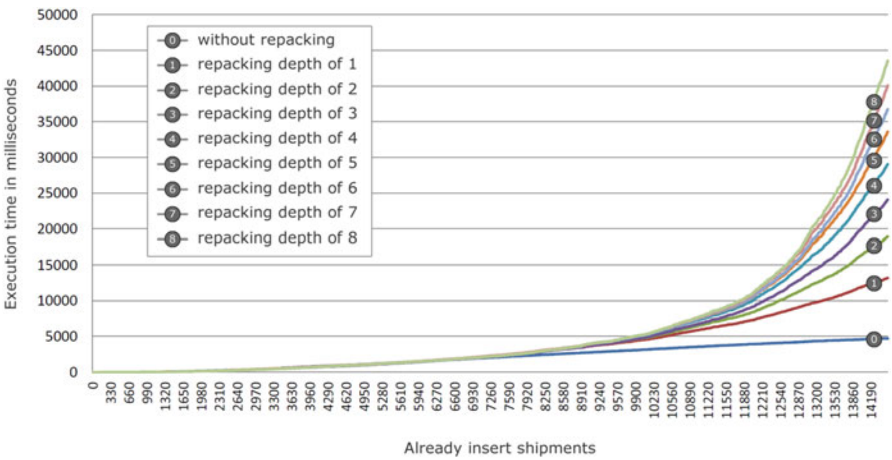


**Fig. 7** Execution time of the RFF algorithms using different repacking depths

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.

## 7 Conclusion and Outlook

In this paper, the problem class m-VRPTWAR developed in [4] and [5] was transferred to the application domain of the "CloudLogistic" concept. For this purpose, the concept was presented in its fundamentals. Based on this description, the basic requirements for the shipment processing within an implied cooperation platform have been developed. By doing this, the shipment processing has been divided into two separate phases. We developed a set of basic requirements for the feasibility check, as well for the final optimization and as well for the pre-processing of the shipment data and their preparation. Based on these requirements, the generation of test data was introduced. In the development of the test data generator, in particular the unique requirements of the multi-staged shipment processing were considered.

By using the described generator tool different realistic test scenarios are generated automatically. These scenarios were used for the evaluation of the feasibility check and the final optimization process.

An extension of the in [5] introduced evaluation of the RFF algorithm was used as an example for using the generated test data to reflect the investigated requirements. In further research it should be deferred to the extension of the first as circular assumed area schema to an elliptical model. Here the used Euclidean approach is converted into a time-based model with isochrones. Also the construction of an index structure for decreasing the number of distance queries and speeding up the whole pre-processing is a focus of future research.

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# Line-Based Optimization of LTL-Shipments Using a Multi-Step Genetic Algorithm

**Christian Tummel, Tobias Pyttel, Philipp Wolters, Eckart Hauck and Sabina Jeschke**

**Abstract** Motivated by the so-called "CloudLogistic"-concept as an innovative, line-based way for dealing with less than truck load (LTL) shipments in cooperation networks, this paper introduces a genetic algorithm as a heuristical approach for dealing with multi-objective optimization problems. Based on the implied optimization problem - the NP-hard multi-depot heterogeneous fleet vehicle routing problem with time windows and assignment restrictions (m-VRPTWAR) - four different optimization goals of the "CloudLogistic"-concept are introduced and a multi-step approach is motivated.

Therefore, two different optimization steps are presented and transferred into a genetic algorithm. Additionally, two innovative problem-specific genetic operators are introduced by combining a generation-based approach and a usage-based approach in order to create a useful mutation process. A further usage-based approach is used to realize a problem-specific crossover operator. The presented genetic multi-step approach is a useful concept for dealing with multi-objective optimization problems without the need of a single combined fitness function.

**Keywords** Genetic Algorithm · m-VRPTWAR · Multi-Objective · Multi-Step · LTL · Generation-Based · Usage-Based · CloudLogistic

## 1 Introduction

In its recent study for traffic linkages in Germany the Federal Ministry for Transport, Building and Urban Development (BMVBS) forecasts a substantial growth of traffic volume in road haulage up to the year 2025 [1]. The long-haul road transportation contributes especially to this trend. A growth of transport volume of about 55 % and an increase in traffic of about 84 % is expected. From the ecological and the economic point of view, these trends should not only be faced with an adjustment of the road network, but also with a more efficient use of the existing infrastructure

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[2]. In Germany, every fifth truck in commercial freight traffic is driving without any load at all [3].

The "CloudLogistic"-concept addresses these challenges and represents an innovative concept for freight cooperation to strengthen the market position of Small and Medium-sized Enterprises (SME) in the long-haul road transportation. The concept tranfers the strengths of already existing general cargo and Full Truck Load (FTL) networks to the area of Less than Truck Load (LTL) transports.

Usually it is not possible for a Small and Medium-sized Logistic Service Provider (LSP), to transport several LTL shipments together in one truck because there are not enough shipments within similar source and target areas. Hence, for a single LSP, several trucks are required for the transport of several LTL shipments. The "CloudLogistic"-concept bundles LTL shipments of several cooperating LSP, via a cooperation network by combining corresponding LTL shipments to generate synergetic effects. Thereby, the concept relies on a line-based logistics model.

On the one hand, the implied optimization problem deals with the assignment of a set of shipments to a certain set of freight routes in order to minimize unused cargo volume of the vehicles by observing some given hard constraints (i. e. time-window-constraint, presented in [4]). On the other hand, this assignment additionally has to observe some other optimization goals like the maximization of quality aspect by choosing higher-ranked LSP for transportation tasks.

After introducing the "CloudLogistic"-concept in detail and after a rough outline about the related work the mathematic model of this concept is transferred into a genetic approach. Afterwards the multi-step approach is presented as an innovative way to deal with the given problem and its differing optimization goals.

## 2 The CloudLogistic Concept

Similar to the IT term "Cloud Computing", the so-called "CloudLogistic"-concept describes the ability and opportunity for LSP to share unused resources by participating in a freight cooperation network. This is done by using its infrastructure, its resources and scaling them locally while sharing their own infrastructure and resources with the network. Several shipments of different network-partners will initially be bundled and assigned to previously established freight routes.

Each route is operated by a partner within the cooperation. For a combined disposition of LTL shipments, freight routes are established, composed of the relation between a source and a target area that is served regularly by several trucks via point-to-point transportation. Trucks are provided by the cooperating partners. Shipments are collected in the source area of the route and then carried directly to the corresponding target area without any turnover at all. In the target area shipments are locally distributed (see Fig. 1). The basic aim of the "CloudLogistic" concept is to determine an assignment of shipments to a certain set of freight routes while decreasing the number of needed trucks, respectively needed FTL capacity. Based on the investigations in [5], the CloudLogistic-approach maximizes the ecological and

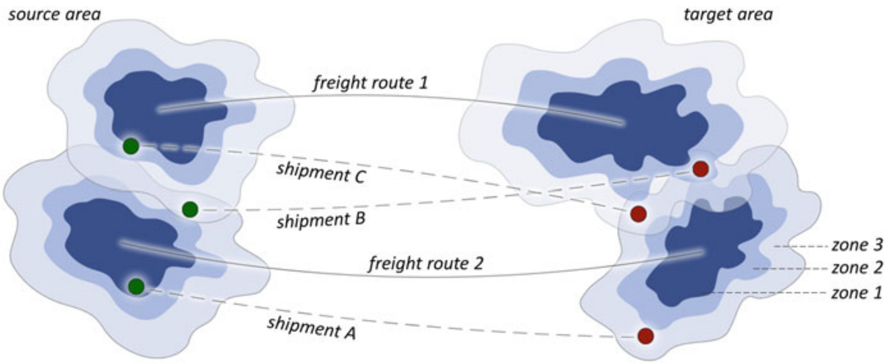


**Fig. 1** Visualization of the implied assignment problem of three shipments and two freight routes

the economic benefits of the overall optimization potential if the main optimization goal consist of the minimization of the needed FTL capacity.

The assignment of shipments to a set of certain freight routes by minimizing the number of used trucks is classified as a NP-hard optimization problem [5]. The problem is illustrated in Fig. 1. First, shipment A is pushed into the system - which can only be assigned to freight route 2. In contrast, both routes are feasible for the transportation of shipment B. If shipment B is assigned to freight route 1 and freight route 2 does not have sufficient unused capacity, shipment C may not be delivered because C can also only be assigned to freight route 2. The number of such collisions increases, if the source and target areas of multiple freight routes overlap and additionally a large number of corresponding shipments have to be distributed.

## 3 Related Work

Vehicle routing problems have always been the subject of research since the first works on this issue by [6]. In [5] a multilevel solution method has been introduced for the “Multi-Depot Heterogeneous Fleet Vehicle Routing Problem with Time Windows”. At first, the algorithm determines reasonable clusters of nodes by using a heuristical approach and afterwards distributes them on a couple of trucks in a valid way by solving a Mixed Integer Linear Program (MILP). This method is able to solve problem instances with up to 100 nodes, but the deviations from the optimal solutions are at up to 30 %. Furthermore, the solution method neither takes the assignment restrictions into account nor is the aim of a minimization of unused cargo volume considered.

The same problem class was covered by [7], this work does not focus on the development of a solution, but the development of an efficient mathematical formulation of the problem model was concerned. At the beginning, a compact MILP is described and extended by specific rules that reduce the size of the MILP (measured by the number of variables). It shows, that this could significantly decrease computation time. Considering the more general problem class of the "Vehicle Routing Problem with Time Windows" (VRPTW), the papers [8–10] and [11] may be consulted.

Solving VRPTW problems by using genetic algorithms, has been subject to many approaches in the past. [12] investigates genetic algorithms as a heuristic for obtaining near optimal solutions. Therefore, a collection of new crossover operators, summarized under the Cross #1 (MX1) and Merge Cross #2 (MX2), are introduced. More conductive optimizing has motivated designing these operators.

Thangiah presents GIDEON in [13], a cluster-first route-second approach for solving the VRPTW within two steps. In a first step a genetic algorithm is used to cluster customers into sectors with additional post-optimization in a second step. GENEROUS representative standing for GENEtic ROUting System was described in [14]. In detail, the representation step makes use of a stochastic selection using a linear ranking scheme to bias the selection process towards the best solution. Further, in the recombination phase, both the sequence-based and the route-based crossover are described in connection to the genetic approach solving the VRPTW. In terms of mutation, three types of mutation operators, their advantages and their necessity are presented. A "Parallel Hybrid Genetic Algorithm" was developed in [15]. The goal of this approach targets is to be fast, cost-effective and highly competitive. This new concept of "co-evolution of two populations" distributes the assignments of minimization of the total traveled distance and generating feasible solutions to two populations. Because the size of the second population, which is in charge of finding feasible solutions, is one less than the size of the first population, only smaller feasible populations are transferred to the first population and these overwrite older versions. Moreover, an insertion-based crossover, a reinsertion crossover operator and a suite of six mutation operators are proposed. As a continuative reference according to [15] [16] can be consulted.

[17] illustrates a parallelization of a two phase procedural approach, consisting of a (1, $\lambda$)-evolution strategy for minimizing the number of vehicles and a tabu search algorithm for minimizing the total distance. Related to the parallelization above [18] can be consulted as similar work in this direction. K. C. Tan et al. use a messy genetic algorithm (mGA). Besides the motivation of usage of a mGA the Cut and Splice Operators are highlighted. Furthermore, the authors cater to the coding and to compare with competing heuristics. The basics concerning messy genetic algorithms can be taken out from [19]. A genetic algorithm within a hybrid search algorithm, in cooperation with a variable intensive tabu search was presented in [20]. This work consists of two new genetic operators leaned on the natural phenomenon of dominate und recessive existence of genes. In [21] a parallel cooperative multi-search procedure - based on the solution warehouse approach - was proposed for finding a good solution according to the VRPTW. Therefore, the authors described important cooperating methods to which genetic algorithms belong.

In one of our latest contributions we introduced the m-VRPTWAR ([5]), which was the first contribution in this specific direction. This problem deals with an assignment of a certain set of shipments to a set of freight routes that minimizes the unused cargo volume of the vehicles. The assignment of each shipment is restricted to a subset of 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 Integer Linear Program (ILP) formulation and first calculation results for an optimal solution to the problem can be found in [5]. Furthermore, a heuristic approach for evaluating the feasibility of an instance of the m-VRPTWAR was presented in [22].

## 4 Terms and Definitions

To build the following remarks on a solid mathematical framework, at first it is necessary to define some fundamental terms according to the definition in [5]. Afterwards these can be used to introduce the genetic approach.

**Definition 1**
*A* **timestamp** $t \in \mathbb{N}$ *is a non-negative integer, that references a specific point of time. All timestamps share a common foundation (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**
*An ordered pair* $A = \langle \lambda, \varphi \rangle$, *whose 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. Furthermore*, $\mathbb{W}$ *denotes the* **set of all geographic locations**.

**Definition 3**
*A function* $d : \mathbb{W} \times \mathbb{W} \rightarrow \mathbb{R}$ *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 is always 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 must not decrease the distance*

**Definition 4**
*Let* $A, B \in \mathbb{W}$ *be two geographic locations,* $\overline{r} \in \mathbb{R}$ *a real number and* $d : \mathbb{W} \times \mathbb{W} \to \mathbb{R}$ *a distance function. Then the set* $G_{A,B,\overline{r},d} = \{X \in \mathbb{W} \mid d(A, X) + d(X, B) \leq \overline{r}\} \subset \mathbb{W}$ *is called* **area**. *In this case* $A, B$ *are called* **focal points** *of this area. Furthermore, let* $\mathbb{G}$ *denote the* **set of all areas**. *The shape of this area is significantly different by the choice of its distance function. For example, a function which calculates the Euclidean distance between two geographic locations differs significantly to a function which determines the time that is needed to reach one geographic location from another when using the road network. In the CloudLogistic concept, the second type of distance function is chosen and called* $d_t$. *So the* **shape of the area** $G_{A,B,\overline{r},d_t}$ *describes an elliptic isochrone.*

Now, we extend the definition of an area according to a multizone-approach. This approach is needed to realize different optimization goals presented in Sect. 6.1. The multizone-approach is illustrated in Fig. 1.

**Definition 5**
*Let* $G_{A,B,\overline{r},d}$ *be an area. Further let* $Z = \{z_1, z_2, \ldots, z_n\}$ *be a set of n distances with* $0 < z_1 < z_2 < \ldots < z_n = r$ *and* $n > 1$. *We call* $G_{A,B,\overline{r},d,Z}$ *a* **multizone-area**.

**Definition 6**
*Let* $V \in \mathbb{W}$ *be the source location of a shipment,* $E \in \mathbb{W}$ *the target location of a shipment,* $w \in \mathbb{R}$ *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 as* $\mathbb{S}$.

**Definition 7**
*Let* $G^s \in \mathbb{G}$ *be the source 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* $\tau$ *by*

*exactly one truck. If the relation between start and target areas has to be served by k trucks, each one of these 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 8**
*A* **set of assignments** *is a function $z : \mathbb{S} \rightarrow \mathbb{L}$ with $z(s_i) = l_j$, if $s_i \in \mathbb{S}$ is transported by freight route $l_j \in L$ with $i, j \in \mathbb{N}^+$. A* **valid set of assignments** *is given if the set holds for all given hard constraints. A collection of relevant hard constraints is presented in* [4].

## 5 A Genetic Approach

One of the significant steps for the development of a genetic approach is to transfer the mathematical model into genetic language consisting of genes, chromosomes, and the population. So in computer-aided problem solving, using a genetic algorithm, the problem has to be encoded in computer-usable syntax. In order to get a suitable encoding, two important guidelines should be kept in mind:

- Similar candidates representing possible solutions should have a similar fitness
- and if possible, the solution space (set of all candidates representing possible solutions) should be closed in connection with the used genetic operators (Fig. 2).

The following definition abstracts the above introduced optimization problem into computer-usable, linked integer values considering these guidelines.

**Definition 9**
*Let $\mathbb{S}$ be the* **set of all shipments** *and let $\mathbb{L}$ be the* **set of all freight routes**. *Furthermore, let $z : \mathbb{S} \rightarrow \mathbb{L}$ be a set of assignments according to the previous definition and the set $M = \{z \mid z \; is \; valid\}$ the set of all valid sets of assignments. Then z implies explicitly the following set of tuples which contains all pairs of indices of shipments to freight routes:*
$z' = \{(i, j) \mid z(s_i) = l_j, z \in M, s_i \in \mathbb{S}, l_j \in \mathbb{L}\} \subseteq (\mathbb{N}^+ \times \mathbb{N}^+)$. *The set $M' = \{z' \mid z \in M \; implies \; z'\}$ is called the* **solution space** *of the genetic approach and represents all valid sets of assignments of shipments to the available freight routes. So a single $z' \in M'$ is called* **chromosome**, *$g \in z'$* **gene** *and $p \subseteq M'$* **population**.

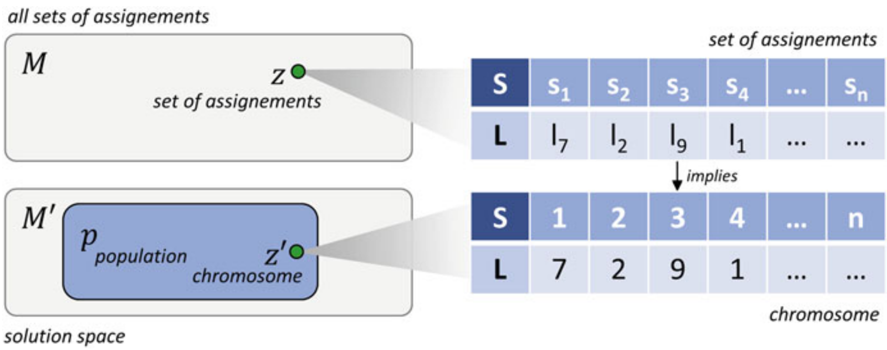


**Fig. 2** Example of the genetic representation

An alternative approach to describe the scenario with a genetic representation, could have been done by using the map $\mathbb{L} \rightarrow \mathcal{P}(\mathbb{S})$ instead of using a representation based on $\mathbb{S} \rightarrow \mathbb{L}$. In this case, a specific truck with its assigned shipments is represented as a single gene. By changing only a single gene of such a representation (for example, in the case of a simple mutation or doing a crossover), the new chromosome does not represent a valid solution, because a single or some shipments will not be assigned or would be assigned twice to a specific truck.

By the use of the above representation, we designed a direct correlation of a shipment to its vehicle. Here the solution space is closed using the specific genetic operators while observing some given hard constraints (i. e. capacity constraints, which has to check all cases). The representation is also conform to the first guideline, because by mutating a single gene, the concerned chromosome's fitness will be changed minimally.

# 6 Multi-Step Optimization

## *6.1 Goals of the Optimization*

In order to specify the genetic approach in more detail (respectively fitness, initialization, selection and reproduction), the main goals of the optimization have to be discussed. In our approach we try to reach four different goals:

- Minimizing the number of needed trucks to reach the highest degree of capacity utilization (**Overall Structural Goal**)
- Maximizing the so-called "fairness" for each truck, if a truck would be used rarely in the past (**Fairness Goal**)
- Maximizing the total quality of the whole assignment by preferring service providers that offered a high quality in the past (**Quality Goal**)
- Minimizing the zone-based distance of each shipment to its source and target area focal points (**Green Goal**)

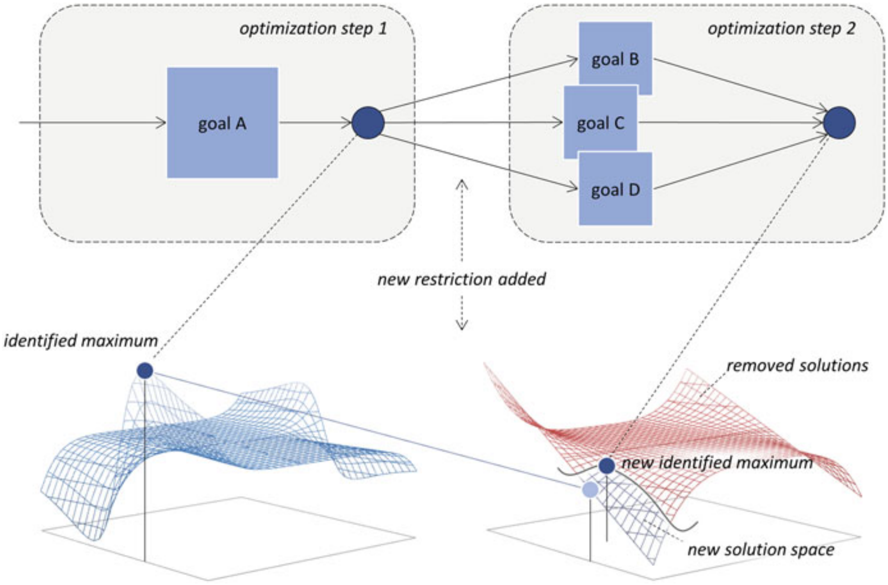


**Fig. 3** Multi-step approach for reaching different optimization goals

These goals were chosen and ranked in different workshops with experts from the logistics segment. Because the **Overall Structural Goal** is essential for the CloudLogistic approach, it must be observed that this goal must be reached with a maximum deviation of 5 % of the best solution that could be found. Therefore, we decided to apply a multi-step approach by dividing the whole optimization process into two separate steps which are illustrated in Fig. 3.

In a first step (described in detail in Sect. 6.1) the optimization process searches for the best solution which minimizes the total number of needed trucks. If the minimal solution is found or a specific time constraint for the duration of this process is reached, the minimal number of needed trucks $n$ is used to specify the solution space of the second optimization step.

By adding an additional restriction in terms of a new hard constraint (only solutions are allowed that use a maximum of $n + 5\,\%$ of $n$ trucks), the solution space is reduced to these solutions which fulfill this condition. Choosing the remaining three optimization goals as a combined goal with weighted subgoals, the implied "fitness-landscape" - which represents the quality of a solution according to the specific goal for the whole solution space - changes in order to represent the new goals. The solution space also changes to a subset of the possible solutions of step one. All other solutions will be removed from the solution space. Then, the optimization process will search for a new solution which maximizes the combined goal of the remaining three optimization goals. The specific weights for the combined optimization goal of step two has been set within the workshops to 0.6 (Green Goal), 0.2 (Quality Goal) and 0.2 (Fairness Goal).

The evaluation of the different goals in detail (i. e. the Fairness Goal) is not the subject of this contribution. At this moment, it is only important to know that the respective estimation depends only on static information which is available without needing further information about the whole solution.

In Sect. 6.2 the first step of this approach will be defined in detail by introducing a suitable fitness function in Sect. 6.2.1, by applying corresponding initialization in Sect. 6.2.2 and selection processes in Sect. 6.2.3, by motivating an innovative problem-specific way for mutation and doing crossover operations for the reproduction in Sect. 6.2.4 and additionally by setting the concerning termination statement in Sect. 6.2.5. Respectively in Sect. 6.3 the second optimization step will be defined in the same way regarding its specific problem definition.

## *6.2 Optimization: Step 1*

### 6.2.1 Fitness

In this optimization step, the total number of needed trucks has to be minimized. In general, a real value $f$ must be defined for the genetic algorithm to evaluate the quality of a specific solution in form of a chromosome according to Definition 9. The so-called fitness of a chromosome is needed to compare chromosomes among each other and enables a selection process according to the "survival-of-the-fittest" principle from Charles Darwin. Hence, to describe the fitness of a chromosome for every encoded solution (chromosome) a real number out of $\mathbb{R}$ has to be defined. The function which gives every chromosome a real number as representation for the quality of the solution is called fitness function. The constitution of the fitness functions of both optimization steps are problem-specific and defined accordingly to different optimization goals motivated in Sect. 6. In the first iteration, the fitness is defined as the quotient of the number of all available trucks to the number of loaded trucks. Thereby, a fitness of a higher value has a better quality than a fitness of a lower value. The determination of these values does not take much computational effort. It is only necessary to count the different truck representatives of each gene for the whole solution. Therefore, a fitness approximation is not needed. The mathematical formulation is given in the following definition.

**Definition 10**
*Let $f_1(z)$ be the fitness of a chromosome $z'$ representing the number of loaded vehicles $\in \mathbb{L}$, then the fitness function is defined as $f_1 : M' \to \mathbb{N} \subset \mathbb{R}$ with $f_1(z') = \frac{|\mathbb{L}|}{|\{j|(i,j)\in z'\}|}$.*

It has to be examined, if this kind of fitness function is applicable in this genetic approach. It is imaginable that another factor i. e. the sum of the load factor of all truck is a better choice to move this approach in the right direction.

### 6.2.2 Initialization

The initialization needs to be provided with a couple of solution. In order to develop a suitable IT-solution for the shipment-processing, which is presented in [4], a first processing step ensures that for every point of time, there will be a known solution in memory. At the beginning of the optimization process this is the only known solution which can be provided. Hence, the pre-processing provides some information that also speeds up the entire optimization process. For example, the determination of possible routes according to a shipment is part of this pre-process. Furthermore, the priority zones according to a shipment on a route are identified in this process. Because the hard constraints must not be violated, this chromosome is just copied $popsize - 1$ time. The size of a population ($popsize$) has to be empirically identified in respect to the total number of received shipments.

### 6.2.3 Selection

The selection of chromosomes transferred into the temporal population is done by the roulette-selection presented by Goldberg [23]. For more detailed information, [24] may be referred to.

Based on the actual population the fitness of each chromosome is calculated. So, a part of the survival probability from each chromosome is built by calculating the average of all fitnesses, followed by calculating the distance of every chromosome's fitness to the average. Then every fitness is added by the greatest negative value of all calculated distances. The survival probabilities are calculated by dividing every chromosomes compensated differences by the sum of all compensated differences. It is obvious that the sum of the survival probabilities must be one. So, a set of real numbers between zero and one is defined and the chromosomes are assigned to this set in the following. Chromosome one is assigned to the number of the above defined set in the range between zero and its survival fitness. Chromosome two is assigned to the numbers of the set in range between the survival probability of previous chromosome and the survival probability of previous chromosome plus the survival probability of this chromosome. This must be continued until every chromosome is assigned to the above defined set.

To choose a chromosome for the temporal population, which has to be reproduced, a random real number between zero and one is created. This number is compared to the above defined set. The chromosome assigned to this number is chosen for the temporal population. This step must be repeated until the wanted temporal population size is reached.

Another selection strategy which has to be evaluated is to select only a number of $popsize - x$ chromosomes to infect the selected population by $x$ additional copies of the best chromosome ever found in all generations.

The advantage of this method is, that good solutions are adopted with a high probability. However, also bad solutions are included in the search and thus, an appropriate measure to escape from local maximum is given. In the following chapter the modification of chromosomes, which requires the generation of the new population out of the temporal population, is described. Therefore, two new problem-specific operators are defined.

### 6.2.4 Reproduction

The reproduction of the selected chromosomes is a critical component of the genetic algorithm and is important to assure a suitable quality of the chosen approach. However, it should be noticed that the chosen operators comply with the defined second guideline in Sect. 5: "The solution space . . . should be closed in connection with the used . . . operators".

By applying operators to chromosomes according to Definition 9, the length of these chromosomes should not be changed. Furthermore, it has to be ensured that a shipment will not be assigned to a route which cannot handle the shipment. This is done by the enrichment of all shipment information with a linked list of all possible routes through the pre-processing step. Beside this, all given hard constraints have to be checked before inheriting chromosomes into the next generation of a population. If these constraints are violated the reproduction has to be repeated.

According to the defined encoding above, while designing the intended genetic operators, the specific optimization goals have to be taken into account. Generally, these operators are divided into the mutation and the crossover process. The mutation will be used to ensure the diversity of different chromosomes in a population. Remembering Fig. 3, this means that starting with a solution on a "hill" with local maximum this solution can be mutated in such a way that the generated mutations are able to lead to a better evolution. In contrast, a crossover operator changes sequences of a chromosome with the sequence of another chromosome. Thus, this operator implies the "climbing" of the actual hill.

The **mutation operator** is a genetic operator which randomly modifies single genes of a chromosome. The decision whether a gene mutates is made by using a mutation probability. On the one hand, solutions out of the whole solution space have to be taken into account to search in the breadth for good solutions. On the other hand, the optimization of good solutions should be improved towards their optimum. So we decided to design a generation-based approach which reduces the mutation probability of each gene according to the runtime of the algorithm.

Besides the generation-based approach a usage-based approach, is used for increasing the efficiency of the algorithm by using the knowledge about the structural conditions to reach the optimization goal more rapidly. This approach additionally

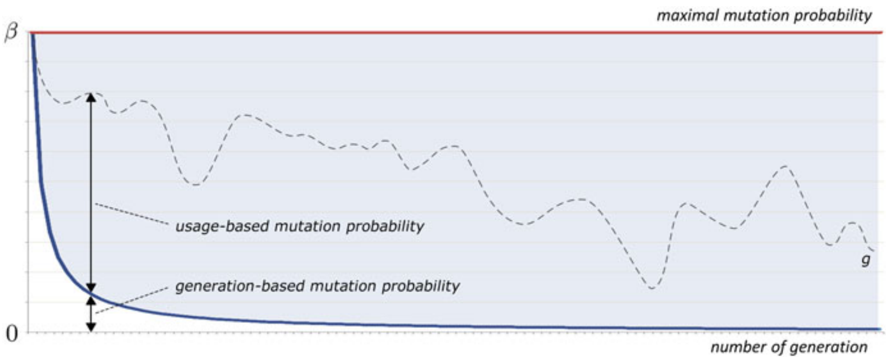


**Fig. 4** Example for the mutation probability of a gene *g* with a generation-based and a usage-based component

manipulates the mutation probability of a gene - described above - by using information about the actual amount of assigned cargo to a specific truck (which is implied by the gene). This chosen strategy aims to identify genes which implied truck is nearly empty and using this information to re-assign the shipment to another truck. The following definition describes the mutation probability of any gene according to the assumptions made above. Figure 4 illustrates the two different probability components of this approach.

**Definition 11**
*Let gen be the number of the current generation and let p be the current population. Furthermore, let* $z' \in p$ *be a single chromosome of this population and let* $g = (i, j) \in z'$ *be a single gene of this chromosome. Additionally, let* $h(j)$ *be the usage in a percentage of the vehicle* $j$*. Then the* **mutation probability of a gene** *g is defined as:* $P_g = \frac{1}{\alpha*(1+gen)} + (1 - \frac{1}{\alpha*(1+gen)}) * \beta * h(j)$ *with* $(\alpha, gen, h(j)) \in \mathbb{R} \times \mathbb{N} \times \mathbb{R}$, $\alpha > 0$, $gen \geq 0$, $0 \leq h(j) \leq 1$ *and* $0 < \beta \leq 1$. *The maximal mutation probability* $\beta$ *of an gen should be in size of* $1/m$ *or lesser, where m is the number of genes. The constant* $\alpha$ *is used to adjust the influence of the time-based approach.*

The **crossover operator** as the second genetic operator is introduced. We choose a truck-based approach, to identify a useful collection of genes for this operation. In the worst case, the usage of a single truck is at 50 % because many genes have to be changed to fill the truck with additional goods or to empty it completely. So this approach identifies a collection of genes which represents assignments of shipments to a truck with a usage of nearly 50 %. By doing this, we ensure that the crossover operation fills a specific truck up with additional shipments.

Figure 5 visualizes this procedure and motivates this approach. In this example, two randomly chosen chromosomes are selected. Truck *a* is identified as a resource

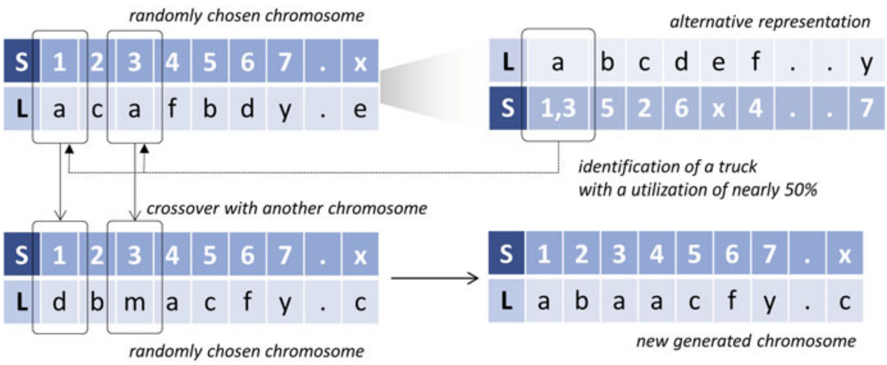


**Fig. 5** Crossover strategy by using the utilization of trucks to identify a collection of genes

with a usage of nearly 50 %. After the crossover procedure, a new chromosome is born where the usage of truck *a* has been grown. According to this approach, we divide the whole procedure of the route-based crossover into the following four steps. These steps will be repeated until every chromosome of the current population are swapped:

1. Select two chromosomes $v_1'$ and $v_2'$ randomly out of the pool of mutated chromosomes.
2. Select from the first chromosome $r$ different truck-ID's $j_1, j_2, \ldots, j_r$. (Choosing the trucks is also done by using a specific probability deviation which prefers trucks with a usage of 50 %.)
3. Swap all genes with $(i, j_1), (i, j_2), \ldots, (i, j_r)$ of both chromosomes for every $i$ by exchanging the genes at the equivalent position.
4. Verify for the new chromosomes that all the hard constraints hold. If there is any violation, $r$ has to be reduced and the procedure has to be repeated at the stage of step two. If the verification of the hard constraints is successful, both created chromosomes are transferred into the temporal population to evaluate their fitness.

### 6.2.5 Termination

The termination criteria of both optimization steps is subject of temporal constraints. The runtime for both steps is bounded by experts from the logistics sector to a maximum of 60 min. That time is acceptable concerning all other corresponding business processes. For a first approach, a time window of 45 min for step one and a time windows of 15 min for step two is supposed.

As a result of the optimization step one, a population with a good fitness is found. That means, we found a solution with a low number of needed trucks. The best known solution now defines the lowest known number of needed trucks $x$. For a further optimization, the best known solutions can be provided beside this interesting index.

## 6.3 Optimization: Step 2

### 6.3.1 Fitness

The second step of the optimization process aims for three hybrid goals: the Fairness Goal, the Quality Goal and the Green Goal (see Sect. 6.1). After the termination of step one (see Sect. 6.2.5), the index $x$ is provided to redefine the available solution space according to the approach explained in Sect. 6.1. To ensure that optimization step two only finds solutions which respect the lowest found number of trucks $x$, a new restriction is added in form of a hard constraint - also described in Sect. 6.1.

**Definition 12**
*To define a fitness function for this step, three individual fitness functions for every subgoal have to be built and normalized. At this time, we assume that such functions for each goal are given. Then the fitness function is defined as function* $f_2(v') = 0.6 * f_{green}(v') + 0.2 * f_{quality}(v') + 0.2 * f_{fairness}(v')$ *using the weights mentioned in Sect.* 6.1.

### 6.3.2 Initialization

To initialize optimization step two the solutions of the last population found by step one are stored after its termination as the initial population for step two. But only those solutions of those which even hold the new hard constraint will be used further. Consequently, the $popsize$ of the new population is lower or equal with the $popsize$ of step one. To reach a specific $popsize$ some chromosomes will be duplicated randomly. The choice of a suitable $popsize$ will be subject to our further work.

### 6.3.3 Selection

To select chromosomes and to transfer them into the temporal population refer the roulette selection by Goldberg, which is described in Sect. 6.2.3.

### 6.3.4 Reproduction

The hybrid character of the combined approach make it hard to define useful problem-specific genetic operators. The individual goals are too different to create any genetic operators which enrich the mutation or crossover process with the use of additional knowledge. Therefore, we decided to use a simple mutation with help of the introduced roulette selection by Goldberg. Also the used crossover is a k-point-crossover described in [24]. This operator uses a defined constant crossover probability which decides the probability for crossover for every gene of a chromosome.

### 6.3.5 Termination

As explained in Sect. 6.2.5, the algorithm has to terminate after a runtime of 15 min. After reaching this limit the solution with the best identified fitness is chosen as the best solution for the multi-step approach.

## 7 Conclusion and Outlook

In this paper an innovative way for dealing with multi-objective optimization problems has been presented. By introducing four different goals of the "CloudLogistic"-concept with its individual requirements a multi-step approach has been motivated. It has been shown, that the presented method is a suitable approach for dealing with different kind of goals by dividing them into two independent steps. For the first step, two innovative problem-specific genetic operators have been created. Therefore, a generation-based approach and a usage-based approach have been combined to create a useful mutation procedure. Furthermore, a usage-based approach has been used for realizing a problem-specific crossover operator. This step has two outcomes: An upper bound for the single goal and a couple of good solutions for entering the second optimization step. By choosing the investigated upper bound as a new hard constraint, the second step has been enabled to search for suitable solutions regarding to the other optimization goals while reaching the goal of the first step within its defined boundaries.

The evaluation of this concept has to be subject of further works. Especially the empirical research for choosing suitable $popsizes$ and for refining the specific parameters of the generation-based/usage-based approach have to be evaluated. Moreover, this approach has to be transferred to other multi-objective problems with similar requirements to elaborate the flexibility and the suitability for daily use.

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# Part IV
# Target Group-Adapted User Models for Innovation and Technology Development Processes

# A Virtual Collaboration Platform to Enhance Scientific Performance within Transdisciplinary Research Networks

**Tobias Vaegs, Claudia Jooß, Ingo Leisten, Anja Richert and Sabina Jeschke**

**Abstract** Scientific collaborations are getting more and more complex and transdisciplinary, as even demanded by many research funding sources. An example is the funding priority "Innovative capability in demographic change" initiated by the German Federal Ministry of Education and Research (BMBF). Several collaborative projects investigate different parts of an overall research problem. These transdisciplinary research networks bring together very different institutions from academia and practice leading to many heterogeneous consortia investigating complex research questions. To discover potential synergies in such research networks means of supporting (physical as well as virtual) networking and collaboration are needed. There is no need to unify the inherent heterogeneity within these collaborations, but researchers must be enabled to learn and benefit from the given diversity. To meet this challenge a variety of different methods is used to enhance learning opportunities for the funding priority in the physical and above all in the virtual world. This paper describes the efforts to support the communication and cooperation within the funding priority and beyond. These efforts especially manifest in the virtual learning and cooperation platform designed for this very purpose.

**Keywords** Cooperation Platform · Research Network · Transdisciplinary · Metaproject

## 1 Introduction and Problem Statement

Innovation is popularly considered the promoter of success in economy and society. In Germany, a large part of the added value is generated with research- and knowledge-intensive products and services [1]. However, to stay innovative, a society needs competent people and flexible companies [2]. Employees need to be both supported as well as challenged in their work process. This becomes even more

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demanding when paired with the effects of demographic change on the working environment. However, these developments offer a lot of opportunities, which need be identified and seized [3].

The funding priority "Innovative Capability in the Context of Demographic Change" of the research and development (R&D) program "Working – Learning – Developing Skills. Potential for Innovation in a Modern Working Environment" of the German Federal Ministry of Education and Research (BMBF) is an example for a scientific cooperation structure investigating these opportunities. The governance of this structure proves challenging because of the complexity of its research topic as well as the diversity of its transdisciplinary members [4]. The metaproject "DemoScreen" supports the communication and cooperation within the funding priority as well as with external addressees. To cope with its diversity and large geographical distribution, a virtual tool of connecting the members of the funding priority is designed. Support of only the physical exchange would leave out some opportunities for networking and the discovery of synergies and lacks the flexibility that comes with virtual collaboration enhancing tools.

This paper will show how the learning and cooperation platform developed by the metaproject can support the cooperation processes within the funding priority and beyond. It is structured as follows: In Sect. 2, current approaches supporting the communication and cross linkage of complex scientific cooperations are discussed. Section 3 explains the funding structure, in which our research subject, namely our funding priority, is embedded. The approach taken to tackle the challenges arising from the diversity of the research subject is described in Sect. 4, together with the corresponding efforts of the metaproject to tackle them. The envisioned cooperation and learning platform, which serves as a prototype method to achieve the goals set for the metaproject, is described in Sect. 5. Finally, Sect. 6 concludes the paper and gives an outlook for further platform functionality and corresponding research efforts in the direction of increasing the learning capability of the funding priority by supporting the communication and collaboration between its members.

## 2 Existing Tools to Assist Communication and Cooperation

The geographic distribution of the members of the funding priority makes it necessary to use electronic tools and other virtual means to support the exploitation of synergies within. There exists a plethora of electronic tools which are supposed to assist communication and cooperation in various groups of people without requiring physical contact. Because the metaproject's goal is to support exactly these processes, tools belonging to the two sets *collaborative software* (groupware like e. g. Sharepoint, Confluence or Viadesk) and *social (research) networks*(e. g. LinkedIn, ResearchGate, but also Yammer and Socialcast) are considered in this section.

In the former set the solutions are in principle suitable for research as well as other business work [5]. Tools from the latter set, however, are usually tailored to the needs of either the business world or the world of academia and find their main users in these domains. The authors of [5] give an overview over a number of examples for the research world, while [6] provides a further investigation of the most prominent ones (e. g. ResearchGate, Mendeley or Acamedia.edu). In [7] common examples from the business world (e. g. CompanyLoop, LinkedIn or XING) are shown.

Existing groupware solutions try to assist collaboration mostly by enabling joint document creation or information aggregation and dissemination within an organization. These solutions usually do not tackle the specific needs of cooperations between transdisciplinary project partners, e. g. the problem of misunderstandings due to differing fields of specialization. In the business world, specific tools are usually used to establish a company language with clear definitions for key terms every employee has to follow to achieve a consistent communication of the company. This is especially important for businesses working with texts, e. g. in translation or technical documentation where terminology has to be unified.

In meta-structures like the investigated funding priority, no central management authority exists, which could enforce a unification of terminology as in a company. In addition, the focus in such diverse structures must be to make members aware of differing terminologies and to give them the opportunity to learn from the given diversity. Different collaborative projects have different perspectives on the same research subject (e. g. innovative capability) and may have a different understanding of certain terms due to their disciplinary constellation. These different perspectives can stimulate each other, but only if everybody is clear about the meaning of used terms and aware of the fact that meanings can differ from perspective to perspective.

Furthermore, there exist platforms especially designed for connecting people (coworkers, people from the same field or specifically scientists) and for supporting their professional networking activities. Basically being social networks for a specific group, these solutions focus on individual people and their affiliations and professional activities. Collaborative projects or even more complex structures like our funding priority are often difficult to map in these platforms, because if any kind of group system exists, usually the possibilities of group hierarchies are limited. Moreover, representatives from the business world are usually not present on research platforms and vice versa, making them unsuitable to connect researchers with practice partners.

Besides the need for a tool to foster professional connections between people, the goal is to bring together academia and business. Hence, one needs a virtual community, which incorporates the needs of both worlds. On the one hand, we want a showroom for our funding priority and its innovative governance structures, where it does not get lost in vast numbers of users from all over the world using it for their private networking (like social networks for the general public, e. g. Facebook). On the other hand, we need ways to promote research activities to addressees outside the funding priority to address future users of the solutions developed during the funding phase. To sum up, existing tools that seem suitable to support transdisciplinary cooperations, do not consider the specific needs of the given application context. The next section explains this context in detail to show, from where its challenges arise.

## 3 The Funding Priority "Innovative Capability in the Context of Demographic Change"

The R&D program *"Working – Learning – Developing Skills. Potential for Innovation in a Modern Working Environment"* (WLD) was initiated by the *German Federal Ministry of Education and Research (BMBF)*. Its goals are to find ways to foster an environment to enable innovative capability in German companies – particularly *small and medium-sized enterprises (SMEs)* – by making them adapt to new technological trends more flexibly [3]. Another focus is to bring together the different worlds of academia and business. The WLD supports approaches to combine the processes of working and learning and to ensure work capability and employability. To meet its own requirements, it is designed as a "Learning Program". This means that after being designed, the program should not run for longer periods of time with the same thematic foci and conditions. Instead it should evolve over time and learn from the findings and experiences made in the process of its execution.

Its learning capability stems from several governance and improvement instruments, which help adjusting the funding policies and topical foci of the program to the current needs of society. Over the duration of the program, several funding priorities are announced one by one in intervals of approximately 1 year. According to current needs and pressing problems each priority sets different emphases in the research topics, which are to be funded. Moreover, the different governance instruments ensure a constant feedback loop enabling the BMBF to incorporate lessons learned from all former (maybe not yet completed) funding priorities into the next one [3].

Funding priorities not only initiate a new wave of collaborative research projects (consortia consisting of several subsidiary projects), they also serve as thematic framework for networking opportunities and knowledge transfer between collaborative projects working in similar areas. They are divided up even further to create smaller communities for collaborative projects working on questions more closely related to each other: the focus groups. These can, among other things, serve as a means of presenting research results of group members to internal and external colleagues or help strengthening the group's academic impact through joint publications.

Figure 1 illustrates the funding structure and governance instruments on the different levels starting on top with the political space, which contains different strategic efforts like the High-tech Strategy [2], going over to the level of different R&D programs like WLD, then to the contained funding priorities with their focus groups and down to the collaborative projects and subsidiary projects at the other end of the spectrum. Communication and knowledge transfer has to flow according to the arrows internally between the levels and to external addressees.

In addition to all these collaborative projects, each funding priority has an additional metaproject entrusted with cross sectional tasks concerning all belonging collaborative projects. They help mediating between different projects or focus groups or between projects and external addressees.

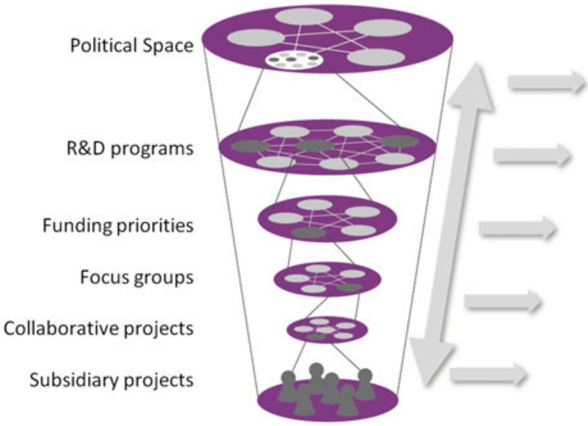


**Fig. 1** The different levels of the research funding and governance structures showing the directions of necessary knowledge transfer

The current funding priority of the program is called “Innovative Capability in the Context of Demographic Change” and focuses on the specific challenges arising from the demographic changes in our population and on means to ensure innovative capability in German companies despite these changes[1]. The significance of this topic is underlined by the fact that the German government announced the Science Year 2013 under the topic “The Demographic Opportunity”[2].

Collaborative projects in the current funding priority investigate problems arising from the increasing diversity in the population regarding age, gender and culture. A society undergoing demographic change is a research field with many facets and dimensions. This makes it necessary to combine impulses from many perspectives when investigating the diverse problems arising from the development in those many dimensions. Concrete research questions are often found at the borders between different disciplines, which were traditionally perceived as very far apart from each other. Therefore, experts from different areas all need to contribute their own specific knowledge, experience and perspective on the problem at hand. Hence, to investigate those questions, a consortium with partners from different disciplines has to be formed. Moreover, the BMBF explicitly demands not only interdisciplinary but even transdisciplinary project proposals. By this, businesses, for which solutions are supposed to be developed, are integrated into the research process right from the beginning. This enables them to contribute their specific requirements and experiences, which helps the researchers to increase the overlap of needed and developed solutions.

In such transdisciplinary cooperation structures one often has to cope with interface problems between the different specializations of the project partners. Scientific methods, conventions and working principles are supposed to complement each other

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[1] Official announcement: www.bmbf.de/foerderungen/15043.php.

[2] Cf. www.demografische-chance.de.

but often collide. If the complexity and diversity inside the consortium is not considered by its management, the result can be friction losses possibly together with more serious problems. This gets even more challenging when the different partners not only stem from different scientific disciplines but also from completely different working areas (i. e. research and practice).

## 4 Virtuality as Approach to Cope with Diversity and Complexity

According to the findings of the monitoring project of WLD called *"International Monitoring" (IMO)*, successful knowledge transfer can be fostered not just by letting information circulate but by qualifying people to successfully transfer and autonomously apply given knowledge. The traditional idea of an expert teaching a layman has to be disregarded and instead the concept of increasing knowledge via communication and interaction between equal partners has to be embraced [8]. To create an environment that supports innovative research and development, IMO suggests four cross-sectional tasks with corresponding research fields [9]:

- Operationalization and Measurement: These efforts aim at the formation, delimitation and measurement of the concepts investigated by the funding priority and at fostering a common understanding of key terms as well as of evaluation factors to create a comparable operationalization of research performance.
- Method integration and Target Group Adaptation: In this area the sensitization for methodical differences between fields of specialization as well as between academia and business world and the enabling of overcoming those differences are emphasized.
- Enabling and Dissemination: Here members of the funding priority need to be qualified to disseminate findings to external addressees and enable them to utilize the results for their practical problems. Qualification on both sides is necessary to turn away from the traditional expert layman teaching principle.
- Cross-Linkage and Constitution of Alliances: Efforts in this area aim at creating processes and infrastructure for physically as well as virtually connecting people inside the funding priority and beyond to increase common learning opportunities and help carrying scientific solutions into practice.

The metaproject picks up on these tasks and fills them with concrete actions. All of them must be tackled not only on the physical level but also using virtual means, which prove more flexible and capable to cope with the given heterogeneity. Especially when supporting cross-linkage and the constitution of alliance one is confronted with very practical physical limitations.

The diversity of the network of researchers regarding not only their field of specialization but also work culture, schedules and location poses special requirements on the creation of opportunities for physical networking and communication. Hence, there is high potential in virtual means of connecting the different researchers and practice partners both within the funding priority as well as to external addressees.

A lot of proved means exist for physical cross-linkage, which among other fields we investigated in a former metaproject [10]. Compared to this, experiences with virtual cross-linkage are usually quite scarce. This is where we see an interesting and promising field of research. Used tools for virtual cross-linkage are often examples from the set of (public) social networks [11]. Hence, in the current metaproject we want to focus on virtual means of cross-linkage.

The approach taken to support researchers and practice partners in these areas is the creation of a virtual learning and cooperation platform for the whole funding priority. It connects the different focus groups, collaborative projects and subsidiary projects and the people involved in them. Next to portraying the funding priority and its efforts to the outside world, it supports the communication of findings between its different actors and thereby their collaboration and cooperation.

Of course, physical networking takes place as well on meetings of collaborative projects, focus groups or the whole funding priority, and such networking opportunities are important to connect its members. Virtual communication still cannot substitute meeting colleagues in person, which includes communication chances, which are very hard to achieve virtually (e. g. casually chatting in coffee breaks). Physically sitting together, collectively compiling results in structured workshops and bonding as a team cannot create the same experience and effects when replicated virtually. However, the inherent diversity of the structures needed to cope with the challenges of demographic change call for an approach which supports cooperation despite this diversity. By lowering the needed effort to overcome borders between different disciplines or between academia and practice, transdisciplinary cooperation can become more effective.

The combined efforts of physical and virtual cross linkage – specifically the efforts manifested in the learning and cooperation platform – aim at supporting the communication and cooperation inside the funding priority. All this work aims at stimulating its learning processes and supporting its learning capability.

## 5 The Learning and Cooperation Platform

Next we explain what has to be done in the four cross sectional areas identified by the monitoring project IMO and how the platform contributes to the corresponding tasks. Its focus lies on connecting the different actors of the funding priority (cross-linkage and constitution of alliances). However, with this connection as a basis there exist a lot of promising opportunities for tackling the other tasks as well. With these efforts the platform not only supports the (collaborative) creation of solutions but foremost their dissemination, internally and to their users in practice.

### 5.1 Operationalization and Measurement

Innovative capability and demographic change are abstract concepts, which are not easy to define commonly [12]. Companies, which are supposed to apply the methods developed in the funding priority, usually need to measure the direct or indirect benefit of certain actions to increase innovative capability. However, operationalizing these concepts and their interdependencies with other factors proves just as hard as defining them. This makes it very important to foster a common understanding of central terms of these topics among the members of the funding priorities. This helps to prevent blending and dilution of similar terms, makes the internal communication of the funding priority more efficient and can reduce misunderstandings. Moreover, it supports a more consistent external communication.

The learning and cooperation platform not only encourages different collaborative projects to exchange their view on the central terms of their topics. There will be an additional section devoted explicitly to the examination of the terminologies in the funding priority. Here, term definitions will be presented, analyzed, and discussed. This helps researchers and practice partners to become aware of the fact that working in such transdisciplinary cooperation means exchanging knowledge with people possibly having different understandings of certain terms, even of the very central terms of the common research questions. Definitions can be both entered manually as well as to a certain extend derived automatically by analyzing publications and other written results from the work of the collaborative projects.

### 5.2 Method Integration and Target Group Adaptation

The heterogeneity of the funding priority leads to a similar heterogeneity in the methods applied by its members. Every discipline has its own means of supporting innovative capability from their point of view. The goal of such transdisciplinary cooperation must be to integrate all these partial solutions into discipline-spreading holistic methods. They must be adequate to cope with such a complex and emergent phenomenon. However, there cannot be a 'one-size-fits-all' approach, but methods must be adaptable to specific needs of their application and therefore be developed in participation with their users [13].

The learning and cooperation platform serves as a means of exchanging different methods and solutions among the scientists and practice partners of the funding priority. The platform will contain a designated section for this, where projects can offer expertise in their methods. The funding priority members become aware of the different disciplines taking part and are supported in crossing the borders between those disciplines and between academia and practice.

## 5.3 Enabling and Dissemination

For solutions developed in the funding priority to take effect they have to be transferred to people, who can use them to increase the innovative capability of their organization. Next to the practice partners, which are already part of the collaborative projects, other users outside the funding priority have to be acquired. For this, a medium capable of reaching many interested organizations and presenting the developed solution in an informative way is needed. However, simply transferring information about solutions according to the standard expert-layman-teaching model is not enough. It is important to enable the members of the funding priority to make others capable of not only understanding but also using their solutions in their daily work [14].

The platform offers means of supporting the funding priority members in disseminating their findings and collecting feedback about them in an appealing way. While the collaborative projects find means of enabling potential users of their solutions through the platform, the metaproject works to enable the collaborative projects themselves to achieve an effective dissemination. The platform offers creators and users of solutions a place, where they can virtually meet. Since this takes place without the limitations of physical meetings (coordination of time and place), a very broad dissemination with a lot of interaction with various potential users is possible. Virtual learning spaces on the platform will serve as an ideal environment, where the step from a theoretical model solution to an application in practice can be taken successfully and efficiently.

## 5.4 Cross-Linkage and Constitution of Alliances

A dissemination of solutions not only outside the funding priority but also among its members is important to ensure a high quality of results. Funding priority actors learn from each other, solutions can expand on existing ones, and an overview about the distribution of expertise is created. Solutions can directly be applied by the practice partners, and direct feedback from their experience can be given [15]. According to the *Application model for measures and instruments of cross sectional processes in knowledge intensive organizations (ASPO)*, cross-linkage of scientific work, common visions and targets, and common product development are crucial aspects of supporting such cooperations [16].

The platform connects focus groups, collaborative projects and subsidiary projects with each other, but also user groups that are independent from official structures can be founded. Every member can create news and events for their group, collaborative project, focus group or the whole funding priority to disseminate and discuss about own findings or interesting information one came across outside the funding priority. Information about projects and material allowing others to get an insight into project results can be shared; thereby synergies can be revealed and exploited. Practice partners and intermediaries can directly try out and spread solutions, also those developed outside their collaborative project. Many results are furthermore available for everyone visiting the platform without logging in. Finally, news and events are disseminated over social media to reach other interested researchers and organizations, which are not aware of the funding priority.

## 6 First Experiences with the Platform

The experiences with the learning and cooperation platform are very positive so far. The funding priority actors accepted this tool very well, which can be seen by the quite frequent use to gain information about the collaborative projects involved and the topic of the funding priority. New features are usually eagerly awaited and from time to time suggestions are made for improvements of existing functionality or for new application areas of the platform, for example the collaborative composition of documents.

Finding the right contact person or getting a quick insight into the work of the projects are the main application scenarios next to distributing news and events about the funding priority and its topics. Events organized by collaborative projects are promoted here, and important information from the funding agency to the collaborative projects is even communicated over this medium.

## 7 Conclusion and Outlook

The governance of complex transdisciplinary research cooperations poses many challenges. The clashes of the worlds of academia and business as well as the interfaces between different disciplines have a lot of potential for friction losses on the way to usable results. The funding priority "Innovative Capability in the Context of Demographic Change" from the German Federal Ministry of Education and Research serves as a good example for such a challenging cooperation structure. To support the communication and cooperation inside this structure, a combination of physical and virtual means is needed. The findings of the monitoring project of the corresponding research and development program identifies four main task areas for this: "Operationalization and Measurement", "Method Integration and Target Group Adaptation", "Enabling and Dissemination", and "Cross-Linkage and Constitution of Alliances".

The metaproject of the funding priority performs various cross sectional tasks concerning all belonging collaborative projects to support the communication and cooperation inside the funding priority and beyond. It thereby tackles all of these four areas to bring together the different collaborative projects and enable them to make their solutions applicable in practice. The most important channel for this is the virtual learning and cooperation platform developed by the metaproject, which offers functionality to interconnect the members of the funding priority, show their activities and results to each other and external addressees and enable potential users of developed solutions in leveraging them.

In the future, the virtual platform will be extended with further functionalities like the collaborative creation of microtrainings[3] or the automatic screening of publications to enhance the understanding of the terminology inside the funding priority. Further research tasks comprise the investigation of other means to support the successful cooperation between the members of the funding priority.

After having created a platform tailored to its specific needs, the next important investigation will be to see whether this platform can be used for other scientific cooperation structures as well. An example would be the Clusters of Excellence funded by the German research foundation (DFG), which also bring together many researchers from different institutions and disciplines to investigate a common research problem. The question here will be which demands and requirements in such a platform result from the specific and divergent properties of the various cooperation structure, e. g. if they are inter- or transdisciplinary.

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[3] Microtrainings are short learning units (15 min.), which can be used to enable someone interested to use a developed solution/method [17].

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# Cluster Terminologies for Promoting Interdisciplinary Scientific Cooperation in Clusters of Excellence

**Tobias Vaegs, Florian Welter, Claudia Jooß, Ingo Leisten, Anja Richert and Sabina Jeschke**

**Abstract** Scientific collaboration is getting more and more complex and interdisciplinary, which is even demanded by many research funding sources (Bryson, Studies for Innovation in a Modern Working Environment. International Monitoring, 2009). Good examples are the clusters of excellence supported by the German Research Foundation, consisting of many local institutions investigating a common research question from multidisciplinary perspectives. In such networks it is important to have structures that support the cooperation of researchers and the information exchange among them to reveal potential synergies and help exploiting those (Sydow, Management von Netzwerkorganisationen. Beiträge aus der „Managementforschung", 2010). There are already a variety of tools available to assist collaboration in large businesses. However, there exists a lack of software, which is tailored to the specific needs of scientific cooperation structures. This demand is met by our Scientific Cooperation Platform (SCP). As part of the SCP the Cluster Terminologies application tackles the understanding between different scientific fields, i. e. differing terminologies. Our first goal is to capture the current state of terminologies in the cluster by gathering and visualizing information about which terms are used with what definition by whom in the cluster. This will raise awareness of where cooperation like interdisciplinary publications can lead to misunderstandings or the necessity to clarify a common terminology beforehand. The second step is to foster discussions about the terminology among the cluster members both in an informal manner as well as in specific workshops. Definitions for some terms will become clearer in this process, which can even lead to an 'official' cluster-wide definition. For other terms maybe at least an agreement among members from the same field can be achieved. However, for terms, which simply have significantly different meanings in different research fields, the main benefit in the SCP lies in the advanced understanding of the differing terminologies.

**Keywords** Interdisciplinarity · Scientific Cooperation · Platform · Cluster of Excellence · Terminologies · Cluster Management · Knowledge Engineering

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## 1 Introduction and Problem Statement

Research nowadays increasingly demands an interdisciplinary consortium working together on scientific questions, because many complex problems are not solvable by experts from one single discipline [1, 2]. Research questions are often found at the interfaces between different disciplines, which were traditionally perceived as very far apart from each other. For these questions experts from different areas all need to contribute their own specific knowledge, experience and perspective on the problem at hand.

That is why more and more cooperation opportunities arise also in form of funding sources, where interdisciplinary collaboration is needed and explicitly demanded [3, 4]. Examples are *clusters of excellence (CoE)*, which are part of the German excellence initiative[1] [5–7]. In our particular case, the CoE *Integrative Production Technology for High-Wage countries* at RWTH Aachen University is devoted to the resolution of the polylemma of production[2] from a complexity and socio-technological perspective, and the design and operation of economically, ecologically and socially viable production systems in high-wage countries [8].

When working in interdisciplinary cooperation structures in general as well as in our CoE one often has to cope with interface problems. Scientific methods, conventions and working principles are supposed to complement each other but often collide. This usually causes friction losses on the way to results but can even lead to more serious problems if the collaborating scientists are not aware of the differences between their disciplines. In such cases, results might not only be obtained very inefficiently but can even be wrong, not accepted in certain disciplines, or projects can fail altogether. This means researchers in interdisciplinary cooperation structures need ways to become aware of these specific problems and need to be supported when coping with them [9, 10].

One of the most prominent areas, from which these problems originate, is that of terminology. A specific technical term can have slightly or even completely different meanings in different fields of specialization [11, 12]. This leads to possible misunderstandings between coworkers from those fields [13, 14]. In the business world there already exists a plethora of tools, which try to assist collaboration (e. g. Sharepoint, Confluence, Viadesk, Yammer, and Socialcast). However, those solutions mostly just enable information aggregation and dissemination inside a company and only marginally tackle the problem of misunderstandings due to differing fields of specialization. If anything, they establish a company language every employee can

[1] The excellence initiative was started in 2005 by the government and federal states. It is divided into three funding lines: graduate schools, clusters of excellence and future concepts for top-level research. In 2012 its second funding period started.

[2] The resolution of the polylemma of production considers two dichotomies. The first dichotomy between scale and scope describes the contradiction between the realisation of a high variety of customised products and the cost-effective manufacturing of mass products. A second dichotomy exists between plan orientation (the objectives of lower-level entities are highly synchronised) and value orientation (highly dynamic production systems) [8].

learn and has to follow thereafter. For the specific needs of scientific cooperations, where the field-specific languages must not be unified but reflect different views on a research problem, we rarely find solutions with focus on the difficulties of interdisciplinary teams.

Reflection on relevant conferences for knowledge management and terminology work show that most tools derive from the field of translation, thus, mostly companies working in the field of technical documentation or translation are seeking software support to assist their work. These companies usually have very strong needs to always use the same term for a given entity. Moreover, they seek to always apply the same definition to a given term. For such associations they maintain databases advising all members of the company to use certain terms and not to use others. Such databases also provide common definitions for all relevant technical terms as to avoid ambiguity in the company's internal and external communication. These tools can provide a useful input to our work but do not meet the full spectrum of our requirements.

In scientific cooperations terminology must not only stay diverse to ensure innovative inputs from different fields, often unification is simply not feasible. For this it would be necessary that all cooperating researchers accept and use the given tools and the conventions dictated by them. In companies this can be enforced by their management making sure that every employee complies with company standards. The company Fiducia[3] even added the usage of the common terminology to its company codex. However, in scientific cooperation structures such as the CoE this is not practical, since they are usually meta-structures next to the hierarchies inside the various member institutes themselves. Because of the lower authority of the cluster management it is hard to define cluster-wide standards [15]. These standards are likely to be in conflict with conventions or just customs in place in the member institutes. In such cases the approach must be to encourage members and member institutes to question the status quo of their (usually not well-defined) terminology and to join in a discussion about this topic. Our research task is to find out with which means one can enable and enhance this process of discussion and convergence to minimize the additional work load for the cluster members. Apart from regular physical meetings, we propose another means of supporting collaboration and cooperation among cluster members, a common *Scientific Cooperation Platform (SCP)*.

This paper is structured as follows: Next, in Sect. 2, we will highlight the diversity of our cluster in terms of scientific disciplines as well as organizational units and explain our vision for the SCP and its Cluster Terminologies application in detail. In Sect. 3 the process of developing the platform and gathering the terminology data is described. Finally, Sect. 4 concludes the paper and gives an outlook for further research efforts in the direction of cluster terminologies.

[3] http://www.fiducia.de/.

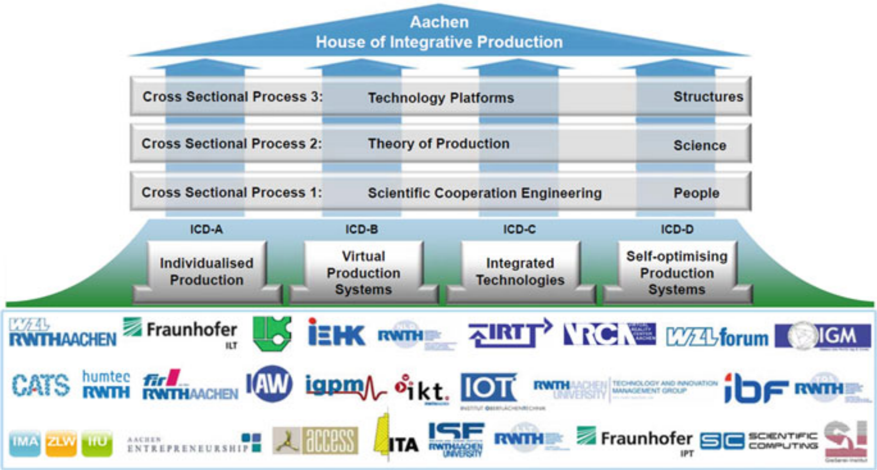


**Fig. 1** Structure of the Cluster of Excellence with its member institutions, topical pillars and cross sectional processes (CSP 1 being our subsidiary project)

## 2 Scientific Cooperation Platform and Cluster Terminologies

The structure of the cluster of excellence (CoE) is illustrated in Fig. 1. The various different member institutions are organized in several subsidiary projects. These projects are on their part grouped into four *Integrative Cluster Domains (ICDs)* to investigate their own subsidiary research problem thereby contributing to the overall research question investigated by the CoE. Apart from the four ICDs there also exist another three subsidiary projects, the *Cross Sectional Processes (CSP)*, which are not part of a single ICD but have interlinking tasks and investigate corresponding research questions.

Our subsidiary project, *Cross Sectional Process 1* (CSP 1 – Scientific Cooperation Engineering) fosters networking and exchange among the cluster members to enable collaboration and discover synergies between the works of different subsidiary projects. CSP 1 investigates ways to support innovation in interdisciplinary and diverse teams as well as ways to operationalize the cluster performance and output to help enhancing it in a cybernetic process. These challenges together with *Knowledge and Cooperation Engineering* form the four fields of action and research in CSP 1. In the latter tools and other means of managing interdisciplinary knowledge and of making it available for all members in a scientific cooperation environment are developed.

Due to the fact that our institute is involved in cross sectional activities and accompanying empirical research since the founding of the CoE in 2006, we were able to analyze the interdisciplinary cooperation of the cluster actors by means of direct and indirect evaluations as well as about 25 structured interviews over the last years. The results were condensed in a prototype model for the management of

CSP, influencing the contemporary project work in the second funding period [6]. Throughout the empirical research the need for action became obvious concerning the following topics: more exchange about cluster terminologies, means of coping with staff turnover and options of searching for experts in the cluster.

This is a central explanation why there exists the need for a common cluster platform, on which members not only get an insight into what other disciplines are part of the cluster, what their scientists are doing and how they do it. It is also one channel for the exchange about the cluster terminologies. Moreover, it eases the integration of new members, and also experienced members stay aware of the cluster diversity.

Our vision of the SCP can be thought of as an online platform, which next to general modules like member profiles, announcements or file server access provides certain functionalities in an app-like fashion. Functionalities like an expert search among the cluster members or an overview about their publication relations are available. Due to a common data and code base the applications are interlinked to be able to access data derived by other parts of the platform. The *Cluster Terminologies* application is one of these applications and helps members to become aware of and cope with differing cluster terminologies.

This application provides cluster members with the possibility of getting an overview over different terms (e. g. for methods or objects), which are supposed to be central terms from research activities of the cluster as well as from the scientific fields involved. Together with these terms the application presents various definitions for each term reflecting the fact that the same term (or very similar terms) can be defined differently depending on the scientific discipline. Every definition is assigned to one or more disciplines and to one or more subsidiary projects of the cluster, where the term is used as the definition dictates. Definitions can also be contrasted with common understandings of the term outside the cluster, if a research topic is examined from a different perspective or in a different way in the cluster.

Reading the data stored for a term, the user directly recognizes how many definitions exist for this term and how ambiguously it is used and understood in different disciplines. Thus, the user learns about definitions from other scientific fields leading to an integrated understanding of the diverse cluster terminologies. Moreover, the application provides the possibility of starting online discussions about every definition. New opinions can be introduced, discussed and if necessary integrated into existing definitions. This way the application's database always contains the current working definition of terms inside the cluster.

The user is provided with different ways of accessing the definitions. Next to a simple alphabetical list or glossary function of the defined terms the user can browse through a structured list of the scientific disciplines which define terms from their perspective. Moreover, the organizational structure of the cluster provides a graphical way of discovering which terms are used and defined in the different ICDs, CSP and subsidiary projects. Additionally, the defined terms are tagged with keywords, which help to examine the terminology on a specific topic.

All this information is gathered, presented and discussed in a persistent way so that it can be established in the cluster instead of getting lost due to staff turnover.

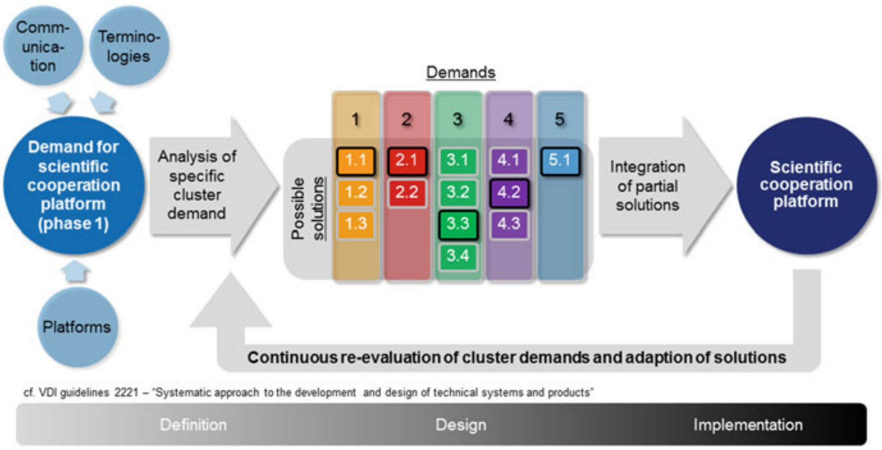


**Fig. 2** Engineering process of developing the Scientific Cooperation Platform for the specific demands of the cluster of excellence

New members can always get a brief overview over the current state of the cluster terminologies. Next we describe our approach to develop the SCP according to the specific needs of the CoE and to gather the necessary data to cope with the problems of differing terminologies.

## 3 Platform Development and Data Acquisition

Figure 2 depicts the general engineering process (according to the VDI guidelines 2221), that was adapted to our knowledge engineering approach and applied for the development of the SCP. In the second funding period we already have experiences from 6 years of project work at our disposal, in which among other results the need for such a platform was revealed [6]. The first task (the problem definition) in the second period is to find out the specific platform demands of the cluster members. One can imagine simpler demands like the possibility of staying informed about current events but also the more sophisticated demand for the possibility of being supported in avoiding misunderstandings among coworkers from different scientific disciplines. In questionnaires evaluating our interlinking work during the first period the cluster members demanded more support for their research collaboration. More precisely, they need support in the areas of communication and terminology, and as the most promising solution they anticipate some kind of common platform.

The different evaluated demands are illustrated by the colored columns in Fig. 2. Solutions for all of them must be found in the design phase, either customized for our needs or developed completely by us. Finally, the solutions have to be implemented and integrated into a versatile and feature-packed SCP. Of course, this is not a single time process, but the cluster demands are regularly re-evaluated over the whole funding period, and the solutions are adjusted accordingly.

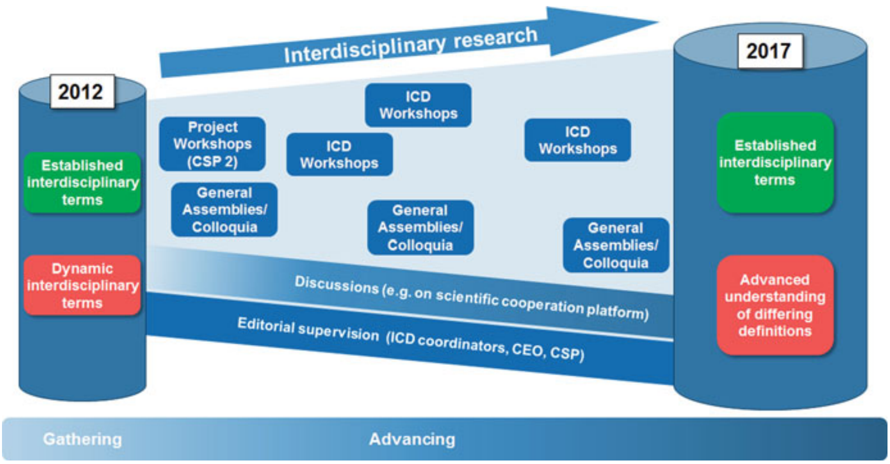


**Fig. 3** Development of the cluster terminologies over the second funding period

In parallel to developing and adjusting the SCP itself the current state of the terminologies used in the cluster has to be determined before the process of advancing the corresponding knowledge base can be started. Figure 3 illustrates our approach for gathering the necessary data from the cluster members. We assume that at the beginning of the second funding period of the CoE (2012) there exists a certain set of established *interdisciplinary terms*. These terms already have established definitions in all or at least many scientific disciplines of the cluster, so that they do not provide a lot of potential for misunderstandings. Not all of these definitions have to exist in written form. It is simply assumed that a common definition for these terms can be found.

In contrast, there also exists a set of *dynamic interdisciplinary terms*, which do not have established definitions. Scientists in the cluster are at odds with each other about how exactly to define these terms, maybe even within the same scientific discipline. However, they might not be aware of this, because nobody has ever tried to come up with a common definition, which also became apparent through analyzing physical meetings and respective protocols. Hence, the first goal is to determine which central terms exist at all in the cluster and which terms belong to which of these sets.

Over the interdisciplinary research activities of the second funding period of the CoE the knowledge base of the terminologies used in the cluster will be advanced. In the end (2017), the set of established interdisciplinary terms is aspired to grow, because the scientists of the research fields using these terms will have discussed about possible definitions and will partly have agreed on common definitions for certain terms as it is explained in the following paragraphs. The process of putting possible definitions in writing and discussing about them already helps making researchers aware of the fact that their disciplines in fact have a very similar view on certain terms.

Moreover, the exchange about definitions enables researchers to realize that often what they believed to be a well-understood, clearly-defined term is actually understood very differently in some disciplines. This then leads to differing definitions for the different scientific fields, in which the term is used. We expect even scientists of one field not always being able to agree on a common definition. In this case the field has to be divided further up and definitions for the different subfields have to be formulated. Ultimately, the set of interdisciplinary terms without common definitions cannot be eliminated, but the platform fosters an *advanced understanding of the differing definitions* of the terms used in the cluster.

Regarding the means of gathering and advancing cluster terminologies, our approach distinguishes between discrete and continuous ones. Discrete means include different forms of physical meetings which will be executed on different levels of integration (subsidiary project level; ICD level; CoE level).

- Throughout project workshops – primarily executed by researchers of CSP 2 to identify contributions to a common theory of production in the CoE – a set of central definitions, methodologies and principles is collected from each subsidiary project that is used as a base set for the Cluster Terminologies application.
- By means of *ICD workshops*, cluster terminologies are advanced by members of the respective ICDs in cooperation with CSP representatives. Here, at least advancing a common understanding for certain terms within a single ICD is aspired.
- During the regular physical meeting form *general assemblies/colloquia*, the development of cluster terminologies can optionally be discussed on the level of the entire CoE to foster a better understanding of e. g. different definitions, methodologies and principles.

Moreover, continuous means of advancing cluster terminologies aim at the discussion and parallel editorial supervision of the cluster terminologies.

- Discussions are enabled due to the interactive design of the SCP, in which the application Cluster Terminologies is embedded. With the opportunity to discuss dynamic terms among all cluster members, the understanding for differing terms is strengthened. Here the combination with incentive systems is planned to foster an active participation in discussions.
- Nevertheless, the continuous editorial supervision of the cluster terminologies (by representatives of single ICDs, the cluster management board or the CSP) will promote the structured advancement of the cluster terminologies.

## 4 Conclusion and Outlook

The challenges arising from interdisciplinary scientific work and the clash of different domains in cooperation structures like clusters of excellence must be eased. For this we propose a Scientific Cooperation Platform (SCP) for information acquisition and dissemination, member communication and workflow assistance. The first origin of difficulties we want to tackle concerns cluster terminologies, where ambiguities in definitions can lead to misunderstandings between scientists working together. By determining the current state of the terminologies, making researchers aware of them and encourage discussions about the possibility of unifying them a common language of the cluster can be fostered. This leads to less internal misunderstandings as well as to a more consistent external communication of the whole cluster.

After evaluating further demands for other applications more functionality will be added to the SCP in general (e. g. new member introductory guide or project progress monitoring) and to the Cluster Terminologies application itself (more ways to access, visualize and use the terminologies). A tool to assist the composition of inter¬disciplinary publications could automatically identify possible sources of misunderstandings according to the planned topic and set of authors. This is one example for an application to assist the members of the CoE in their daily work. Other means to exploit the potential of different text mining technologies on the terminology data gathered from the CoE have to be investigated.

The features of the platform will be customized to the specific needs of our cluster of excellence. However, as soon as it has reached a high level of functionality and sophistication and when we have gathered more working experience with it, we will aspire to expand its use to other clusters of excellence and further similar cooperation structures. For this, it has to be investigated to what extend the requirements in these different structures concur and how much a SCP would have to be customized to other demands.

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# Using Mixed Node Publication Network Graphs for Analyzing Success in Interdisciplinary Teams

**André Calero Valdez, Anne Kathrin Schaar, Martina Ziefle, Andreas Holzinger, Sabina Jeschke and Christian Brecher**

**Abstract** Large-scale research problems (e. g. health and aging, eonomics and production in high-wage countries) are typically complex, needing competencies and research input of different disciplines (Ziefle et al., E-Health, Assistive Technologies and Applications for Assisted Living: Challenges and Solutions, pp. 76–93, 2011). Hence, cooperative working in mixed teams is a common research procedure to meet multi-faceted research problems. Though, interdisciplinarity is – socially and scientifically – a challenge, not only in steering cooperation quality, but also in evaluating the interdisciplinary performance. In this paper we demonstrate how using mixed-node publication network graphs can be used in order to get insights into social structures of research groups. Explicating the published element of cooperation in a network graph reveals more than simple co-authorship graphs. The validity of the approach was tested on the 3-year publication outcome of an interdisciplinary research group. The approach was highly useful not only in demonstrating network properties like propinquity and homophily, but also in proposing a performance metric of interdisciplinarity. Furthermore we suggest applying the approach to a large research cluster as a method of self-management and enriching the graph with sociometric data to improve intelligibility of the graph.

**Keywords** Publication Network Analysis · Sociometry · Interdisciplinarity · Research Cluster Assessment · Bibliometry · Visualization

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# 1 Introduction

Interdisciplinarity is a hyped term when it comes to directions of scientific research [1]. Inter- or transdisciplinary approaches promise breakthrough developments [2] by leveraging method competences from different fields in unison. Scientific teams have been shown to outperform solo authors in knowledge generation [3].

In order to acquire funding for research scientists often need to look into interdisciplinary approaches to solve real world problems [4]. But interdisciplinarity cannot be achieved by simply combining researchers from different fields into a research group. In contrast, interdisciplinarity – though widely acknowledged as a reasonable research procedure from a technical point of view – suffers from diverse cognitive research models across team members, stemming from different knowledge domains, research languages, methods, models, and procedures. Aggravating, as team members are mostly not aware of threes different professional upbringings, team's cooperation is often not perceived as successful or effective by team members [5].

Efforts have been made to understand how interdisciplinarity must be learnt from a socio-cultural, social, cognitive perspective to gain insights on the learning processes of interdisciplinarity as a faculty [6]. It has been found that successful interdisciplinarity requires a conscious effort, time and resources to establish the required interpersonal relationships for effective communication [7]. Successful teams have also been shown to perform better at interdisciplinarity than newly formed teams [8].

But before one can select measures to improve communication effectiveness or interpersonal relationships it is necessary to determine what factors contribute to interdisciplinary success and furthermore what constitutes interdisciplinary success.

In traditional disciplinary research established and widely accepted methods of measuring success exist. But how can one translate measurements like the judgment of an established community for peer review if no established group of peers exists. Quality of outlets by measuring impact factors might also be inappropriate, because young interdisciplinary fields of research have no established outlets, and acclaimed disciplinary focused outlets might reject interdisciplinary publications due to misunderstanding or out of scope problems [9].

Assuming that publications are a measure of disciplinary success, publication cultures differ between disciplines leaving interdisciplinary research without a unified calibrated measure for success [10].

## *1.1 Using Publication Network Analysis to Manage Success*

Understanding how families of scientific disciplines differ has already been analyzed by Publication Network Analyses [11]. Also flows of citations have been used to analyze development of a research field [12] in highly inter- and transdisciplinary field. Web-Based Data mining of publication data can be used to understand how scientific fields progress [13]. Using graph representation for publication analysis suggests itself because of the innate graph-like structure of publications. Inbetweenness Centrality of Journal Graphs has been used as a measurement for interdisciplinarity in outlets [14].

Even if publications are a valuable measuring tool for whole fields of research, how can one identify latent structures that lead to high quality scientific output in specific interdisciplinary teams. Understanding how groups of people are linked and how they can be affected has been studied in the early 1950s with sociometry [15].

Mapping qualitative data (e. g. who talks with whom) to graphs reveals important nodes and possible change agents to influence the whole social network. But what are the implications for interdisciplinary teams? Can one do measuring and steering interdisciplinary research efforts by looking as sociometric data and publication networks [16]? Do similarities exist?

The idea of the quantified self [17] defines a new perspective that uses specific (mobile) applications for measuring parameters (vital or habitual) in order to allow self-management. Whenever something is measured intentionally, the outcome is altered during the measurement (by the awareness for the measurement). This effect is often applied in cognitive behavioral therapy by increasing awareness of the measured dimension. This improved awareness increases self-efficacy and thus improvement in behavior [18]. Can this approach be used to allow steering of research groups?

## 2 Visualizing Publication Networks

The idea for using mixed node graphs for publication network analysis came to us when trying to demonstrate the research efforts of a highly active interdisciplinary research group at RWTH Aachen University (http://www.humtec.rwth-aachen.de/ehealth). The group and its research program started in 2009 (funded by the excellence initiative of German federal and state governments). In order to make research efforts and its success transparent to the German Wissenschaftsrat (the highest scientific board in Germany), we tried to understand how we have worked, why we were successful and what had lead to this development. For this purpose we generated a visualization of our publication behavior. But in order to see the interdisciplinary efforts, we needed something different than simple co-author networks, because the output of the cooperation (namely the publication) should be a part of the representation as well, to match the users mental model [19]. The typical binary co-authorship relationship actually represents an n-ary relationship between n-1 authors and a publication. This is why we tried to use mixed node publication network graphs.

Graph theoretical analyses of bibliometric data usually use single node type network graphs (i. e. all nodes are authors or all nodes are publications). These mostly contain single typed edges (e. g. co-author relationship or citations). The use of mixed node publication network graphs allows a graph to contain more information (than a co-authorship graph) and can easily be reduced to one by using an injective mapping function. Making these entities part of the graph makes visual interpretation easier.

### 2.1 How the Mixed Node Publications Network Graph Is Constructed

The network graph G is constructed with mixed node types. A node either represents an author (A-Node) a publication (P-Node) or a discipline (D-Node). From a graph theory point of view nodes (i. e. vertices) are not regarded as differently. We define three sets representing authors, publications and disciplines:

$$A = \{a \mid a \text{ is author in ehealth research group}\} \tag{1}$$

$$P = \{p \mid p \text{ is publication written by any } a \in A\} \tag{2}$$

$$D = \{d \mid d \text{ is a discipline studied by any } a \in A\} \tag{3}$$

Then we can define three vertex-mappings $f_a$, $f_p$ and $f_d$ and three sets of vertices $V_1$, $V_2$ and $V_3$ as follows:

$$f_a : A \rightarrow V_1, f_a(a) = v; a \in A \wedge v \in V_1 \tag{4}$$

$$f_p : P \rightarrow V_2, f_p(p) = v; p \in P \wedge v \in V_2 \tag{5}$$

$$f_d : D \rightarrow V_3, f_d(d) = v; d \in D \wedge v \in V_3 \tag{6}$$

$$\text{with } V_1 \cap V_2 \cap V_3 = \varnothing \tag{7}$$

We define the sets $E_1$ and $E_2$ and a weight mapping $\omega$ as follows, using that $f^{-1}$ is the inverse of $f$:

$$E_1 = \{e \mid e = (v_1, v_2), v_1 \in V_1 \wedge v_2 \in V_2 \wedge \text{if } f_a^{-1}(v_1) \text{ is author of } f_p^{-1}(v_2)\} \tag{8}$$

$$E_2 = \{e \mid e = (v_1, v_3), v_1 \in V_1 \wedge v_3 \in V_3 \wedge \text{if } f_a^{-1}(v_1) \text{ studied discipline } f_d^{-1}(v_3)\} \tag{9}$$

$$\omega : E \rightarrow \mathbb{R}, \omega(e) = 1, \text{ if } e \in E_1 \text{ and } \omega(e) = 0.5, \text{ if } e \in E_2 \tag{10}$$

Then we define two graphs as follow: $G_r$ we call the reduced mixed node publication network graph and $G_f$ we call a full mixed node publication network graph.

$$G_r = (V, E) \text{ with } V = V_1 \cup V_2 \text{ and } E = E_1 \tag{11}$$

$$G_f = (V, E), \text{ with } V = V_1 \cup V_2 \cup V_3 \text{ and } E = E_1 \cup E_2 \tag{12}$$

The reduced and full mixed node publication network graphs are representations of publication networks that can be visualized using standard graph visualization tools. $G_r$ is a bipartite and $G_f$ a tripartite graph.

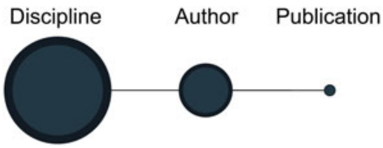


**Fig. 1** Three *node sizes* represent disciplines, authors and publications. *Edges* represent relationships between nodes

## 2.2 Spatial Mapping of the Publication Graph

In order to allow visual analysis by a human person graphs need be lain out graphically. For this purpose we use the open-source software Gephi [20]. Gephi allows graph input by various means (e. g. HTTP-JSON interface) and different layout algorithms.

In this case 2D-spatial mapping is performed by Gephi using it's *Force-Atlas 2* algorithm. Graphs in Gephi allow additional information for graph elements. In particular color, size and labeling can be defined for edges and vertices (i. e. nodes).

For our visualization we set the size of P-Nodes to 10, A-nodes to 50 and D-Nodes to 100 (see Fig. 1).

Using the *Force-Atlas 2* algorithm creates a visual representation according to the following rules:

- All nodes are attracted to the center.
- All nodes repel each other.
- All nodes that are connected by an edge attract each other, according to the weight of the edge (i. e. heavier edges equals stronger attraction).
- Optionally node sizes can be added to the repulsion to prevent visual overlapping.

This allows the following visual conclusions:

- Two A-Nodes are spatially closer if they publish together.
- Two A-nodes are spatially closer if they come from the same discipline.

## 2.3 Temporal Mapping of Graph

In order to understand development of publication networks temporal mappings or snapshots were required. The idea was that according to publication date nodes and edges were sequentially entered into the graph using the JSON interface of Gephi. This would allow programmatically based animated publication graphs.

Timing of insertion is structured (pauses between new years) to give the impression of stretching time, which allows the layout algorithm to further sort nodes spatially. This sorting and inserting is recorded into a video file. The resulting video of the sorting algorithm is then sped up until it fits into a 90-s clip.

In this clip nodes move according to the attractive forces of the continuously running layout-algorithm giving the impression of a birds-eye-view of moving people that group together. The human brain (even in its early infancy) tends to apply agenticity [21] (infer agents behind patterns) if objects move in atypical non-physical motions [22]. This further enhances the impression of persons moving to find their "peer group" in the publication network graph (see https://vimeo.com/48446978).

### 2.4 Benefits of Visually Mapping Mixed Node Publication Networks

Gephi allows for several different graph analyses of network graphs. Traditionally these are used with social network graphs (i. e. co-authorship graphs). Interpretation of graph statistics must be reevaluated for mixed node graphs. Graph statistics that are of interest in regard to publication networks are:

- *Number of Weakly Connected Components* [23] refers to the amount of components that are only weakly connected (i. e. only by directed edges in one direction). In an undirected graph they reflect the number of unconnected communities (i. e. subgraphs).
- *Graph density* reflects to the degree of how connected a network graph is. If the density is 1 all nodes are connected with each other. Higher density means that the network is better connected. For bipartite graphs (like $G_r$) maximal density is limited by:

$$\frac{1}{1+\left(\frac{n-1}{2\,m}+\frac{m-1}{2n}\right)}, \text{ when } n, m \text{ are the cardinalities of the two parts.} \qquad (13)$$

- *Graph Diameter* refers to the maximal distance between any two nodes in a network. The smallest possible diameter is 2 (for $G_r$) and 3 (for $G_f$). When more than one discipline exists in a graph the smallest possible diameter can become 5 (if two authors of two different discipline publish tighter). Larger diameters mean that some authors in the network are not publishing together.
- *Average Path Length* refers to the average length from any node to all other nodes. Larger numbers can mean less cooperation or the existence of highly central nodes (that lie on many paths). It cannot be lower than 1 (for $G_r$) and 2 (for $G_f$).
- *Average Degree* refers to the average of outgoing edges in the graph, represents the average of publications per author mixed with the average of authors per publication. When using $G_f$ one must be aware of the two confounding influences. The average number of authors per discipline and the average number of disciplines per author. This makes immediate interpretation of this value harder.
- *Betweenness Centrality, Closeness Centrality, Eigenvector Centrality and Eccentricity* [24] are measures for nodes indicating how important they are for finding short paths in the network. The Closeness Centrality reflects the average importance of a node when randomly spreading information to the whole network (which might be used to model communication flow), while Betweenness Centrality reflects the average importance of a node to find a shortest path between two specific nodes. Eigenvector Centrality measures the importance of a node for

the total network. Central persons (i. e. Professors) should show high values in Betweenness Centrality, Closeness Centrality and Eigenvector Centrality. Eccentricity refers to the maximum possible distance to any other node for a specific node. It can only be smaller than the diameter and should be high in weakly connected nodes.

- *Modularity and Community Detection* [25, 26] can be used to identify groups in connected graphs that share more edges than randomness would predict. Modularity then measures the amount of how much higher the connections within a community are against connections between communities. Lower values mean that communities interact more with another.

The human mind is capable of analyses that are not computationally easy. Tasks that are relatively easy for the human brain but hard for computers are called "Human Intelligence Tasks" (HIT). Seeing structural changes in a network graph from a metaperspective is one of those tasks (e. g. seeing whether two subgraphs are connected).

Especially interpreting measures like density and centrality is rather hard for mixed node graphs. Visualization makes the interpretation of these measures fundamentally easier. Enriching visualization with qualitative sociometrical data allows for high quality educated guessing in understanding a mixed node publication network graph [27].

## 3 Analyzing the Publication Network Visualisation of the eHealth Research Group at RWTH Aachen University

Two types of analyses are possible: Graph Statistics from Gephi and informed pattern recognition from humans. Both are performed here as an example. As graph data publication data from the ehealth group is used as a full mixed node publication network graph. The term informed is used in this case because social anatomy of the group is well known by the author. The mixed node graph is shown here (see Fig. 2). Furthermore nodes are colored according to the discipline to that they belong.

### *3.1 Graph Statistics*

Applying the Gephi graph analysis reveals the following statistics. The graph contains 14 authors, 6 Disciplines and 198 publications. The average Degree is 3.009 and the diameter of the graph is 6. The average path length is 3.055 Graph density is 0.014. The graph only contains one weakly connected component, which has eight communities and a modularity of 0.512. These results demonstrate a highly interconnected network with short paths between disciplines, authors and publications. In regard to centrality measures (closeness, inverse eccentricity, betweenness and

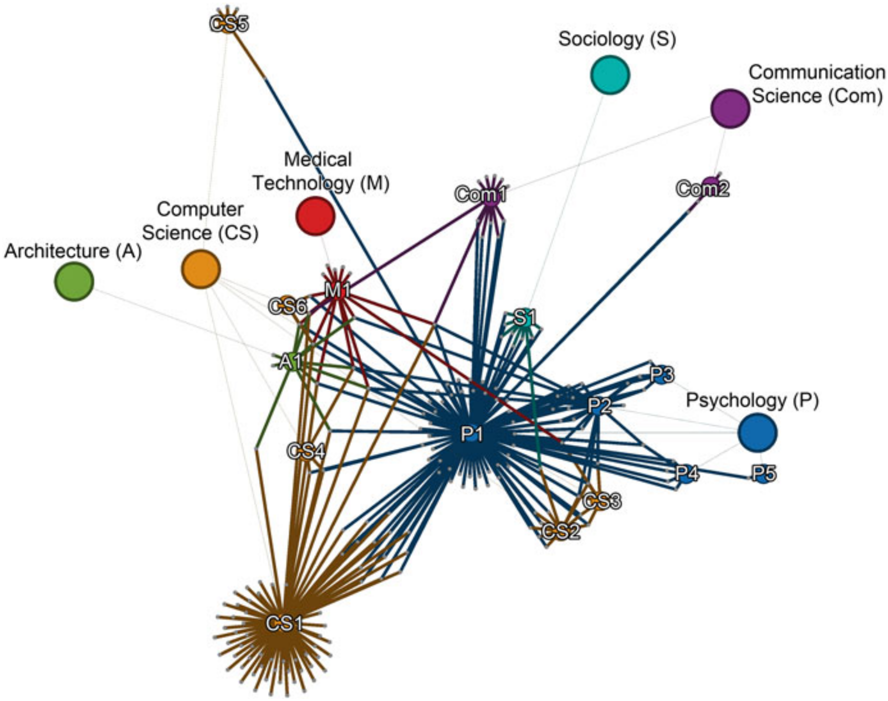


**Fig. 2** $G_f$ for the ehealth programme publication data over 3 years. Six disciplines, 14 authors and 198 publications, (http://www.humtec.rwth-aachen.de/ehealth)

eigenvector), two nodes are prominent P1 (first place in all measures) and CS1 (second place in all measures). Nonetheless P1 and CS1 are dramatically different, as presented in the next section.

## *3.2 HIT-Analysis*

When looking at the animated network graph certain additional factors become obvious, that are hard to see from the statistics point of view. Certain structures become visible which remain hidden from centrality measurements.

In this graph it is obvious that the node P1 plays a structurally important role, which is also predicted by the centrality measures. The node CS1 in contrast is predicted to play an important role, but visually remains on the outskirts of the graph. Looking at the social anatomy of the group reveals why CS1 is not located at the center. The person behind CS1 has had only bi-weekly attendance at the institute, and sits in a single-person office.

Typical social structures reveal themselves in a graph like propinquity and homophily assuming an underlying implicit multiplexity of the edges. Nodes that cluster together come from the same projects (e. g. Com1, A1, CS6, M1, P1), share offices (e. g. CS2, CS3, P2), come from similar discipline (e. g. P1, P2, P3, P4, P5), are friends in their free time (e. g. CS2, CS3) or apply similar methods in their research (e. g. CS2, CS3, P2). Interdisciplinary publication success becomes also visible by looking at the color distribution of the graph. Particularly the group of CS6, M1 and A1 have published very interdisciplinary.

Nodes that are also the outskirts of the graph (COM2 and CS5) are members of the team that have joined our team quite recently.

### *3.3 Additional Insights*

Regarding the user's barriers and fears of new technology (e. g. [28] or [29]) is important. One could have expected that information visualization would have evoked negative and competitive feelings within the group. However, the contrary was the case. When demonstrating the visualization within the group reactions where positive throughout. Not a single member of the team focused on ranking member into a publishing- top-list or anything similar. In contrast members of the group were astonished to see how their publication behavior was so revealing about themselves. Thus, the visualization did evoke additional interest for the group and a hedonic gaming attitude on how to increase interdisciplinary publication behavior as a mean for further team cooperation. For example, some members firstly realized that there are members of the team that shared research interests with them, but have not published together yet. Looking at publications from a revealing of existing and unpublished insights point of view, proved itself to be very helpful. Members reported the visualization be a motivating factor for themselves. This shows that (1) information visualization in form of picturing publication networks can facilitate social behavior and increase team identity and (2) performance measurement does not provoke hostile team behavior, if (1) the reason for the performance visualization is made transparent and (2) the tool can be used as a self-control instrument of the group (rather than by heads only).

## 4 Cybernetic Application of Publication Network Visualization for Interdisciplinary Innovation Management

This lead to the question whether one can apply this approach in a cybernetic way to allow self-measurement to steer a scientific cluster? In order to test this idea, we first created a reduced mixed node publication network graph for the publications of the cluster of excellence (Integrative Production Technology for High-Wage Countries: http://www.production-research.de). The reduced graph was chosen, because no author information on disciplinarity was publically available (see Fig. 3).

**Fig. 3** $G_r$ of publication data of research cluster over 5 years of over 2500 publications and 274 authors. Structures emerge immediately to the human eye

Applying the Gephi graph analysis reveals the following statistics. The graph shows an average degree of 3.766 and a Diameter of 23. The average path length is 8.08. Graph density is 0.005 (maximal theoretical possible density of this graph $\sim 0.18$). Community analysis reveals 28 Communities and a modularity of 0.844.

In regard to node statistics two professors' nodes (located in the center of the graph) dominate the centrality measures with one exception. In regard to eigenvector centrality a node from the node-cluster in the top center ranks third. This node is a bridge node that has many strong ties within his group but also weak ties (which are important for allowing information between node-clusters) to another group.

One must wonder whether social analysis of this graph is possible? From various sources we have heard that the just reported bridge-node is also a person that is seen as interested in various topics, communicative and extroverted. This hint might lead to the conclusion that social structures are hidden in a graph but need to be studied on their won. This graph can only be analyzed and interpreted correctly if underlying social parameters are assessed. This could allow analyzing success factors of central nodes on the fly and allow steering by identifying networking agents or designing cluster specific seminars to enhance interconnectivity within a research cluster.

## 5 Conclusion

Success factors for interdisciplinary research efforts can be measured by looking at publication network graphs. By using mixed node graphs important real world properties are added to the graph, which simplify human interpretation, by making implicit relationships (i. e. co-authorship) explicit (by showing co-authored work).

But in order to give publication network graphs more meaning further data is required. Parameters like impact factors, citation indices should be incorporated from a bibliometrical point of view. From a sociometric point of view properties like personality traits, motivation types, method competences and many more need to mapped to gain further insights. Furthermore recognition of user's requirements for any social application is important [30].

From a graph theory point of view using mixed node graphs might break the interpretability of some of the used graph statistics but the enhancement of visibility outweighs this problem for the time being.

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# Access to UML Diagrams with the HUTN

**Helmut Vieritz, Daniel Schilberg and Sabina Jeschke**

**Abstract** Modern software development includes the usage of UML for (model-driven) analysis and design, customer communication etc. Since UML is a graphical notation, alternative forms of representation are needed to avoid barriers for developers and other users with low vision. Here, human-usable textual notation (HUTN) is tested and evaluated in a user interface modeling concept to provide accessible model-driven software design.

**Keywords** Unified Modeling Language (UML) · Human-Usable Textual Notation (HUTN) · Accessibility · Modeling

## 1 Introduction

Software development is an interesting work for visually impaired programmers and developers. It is mostly text reading and writing based on programming languages as Java or C# and therefore accessible for Screenreaders, Braille devices and other assistive technology. However, writing and testing source code is only one activity among others in the development process. Especially in professional environments, analysis and modeling gain more and more importance with the growth of the project. Beside programming languages, other formal notations are used for the communication between software architect, developer, customer and user. In the last decade, the unified modeling language (UML) [1] became the Lingua Franka in design and modeling of software artifacts. It facilitates the communication for the involved people with formalized and easy-to-understand diagrams such as the use case diagrams. Within UML, a graphical notation and a generic metamodel are combined for object-oriented software modeling. Behavior description is supported by use case or activity diagrams etc. Component or class diagrams allow the description of software structures. Especially UML class diagrams are widely supported by development tools as

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the eclipse modeling framework (EMF), Rational Rose, Magic Draw etc. All these reasons help to understand why UML became the new standard for software design.

But on the other side, the UML graphical notation creates new barriers for some visually impaired people. Diagrams mix up text and graphical information and can be very detailed. Essential information such as object relations is only given by graphical layout. Therefore, without the support of alternatives, the use of UML diagrams is very restricted for software developers with low vision. Thus, a requirement exists to provide accessible presentation alternatives for UML diagrams.

In the next chapters, the state of the art is discussed first. Then, a concept for a text-based notation is used as an alternative for UML diagrams. The results of the evaluation are discussed and finally, a conclusion and outlook is given.

## 2 Related Research

The TeDUB project and Accessible UML [2] provides access to UML based on the XMI format. At first, diagrams are interpreted and then the user can navigate them with a diagram navigator using a joystick or keyboard navigation. Thus, diagrams need an extra transformation for accessible usage. Direct editing of diagrams is not possible.

Different approaches exist to translate visual graphics into haptic presentation. Typically, they are restricted to very simple diagrams. An interesting approach was elaborated by Kurze [3] when haptic presentation was much more powerful if the mental representation by the user is considered.

## 3 HUTN-based UML Notation

### *3.1 Concept*

The presented concept of textual notation for graphic models is part of the INAMOSYS approach in user interface (UI) modeling. INAMOSYS uses UML Activity and class diagrams for the task and presentation modeling of accessible Web applications and product automation systems [4]. Activity diagrams describe navigation; user action and workflow (e. g. see Fig. 1). Class diagrams describe the abstract structure of the UI.

The alternative notation of the task and presentation models aims to have direct access to the design process for users with low vision. Direct access means that the model presentation and manipulation does not need additional transformations. Therefore, the human-usable textual notation (HUTN) [5] was used for UML diagram manipulation. As UML and XML Metadata Interchange (XMI), HUTN is based on the same metamodel Meta Object Facility (MOF) [6] and was developed in 2004 by the OMG. It is intended to provide an easy and quick way for changing details

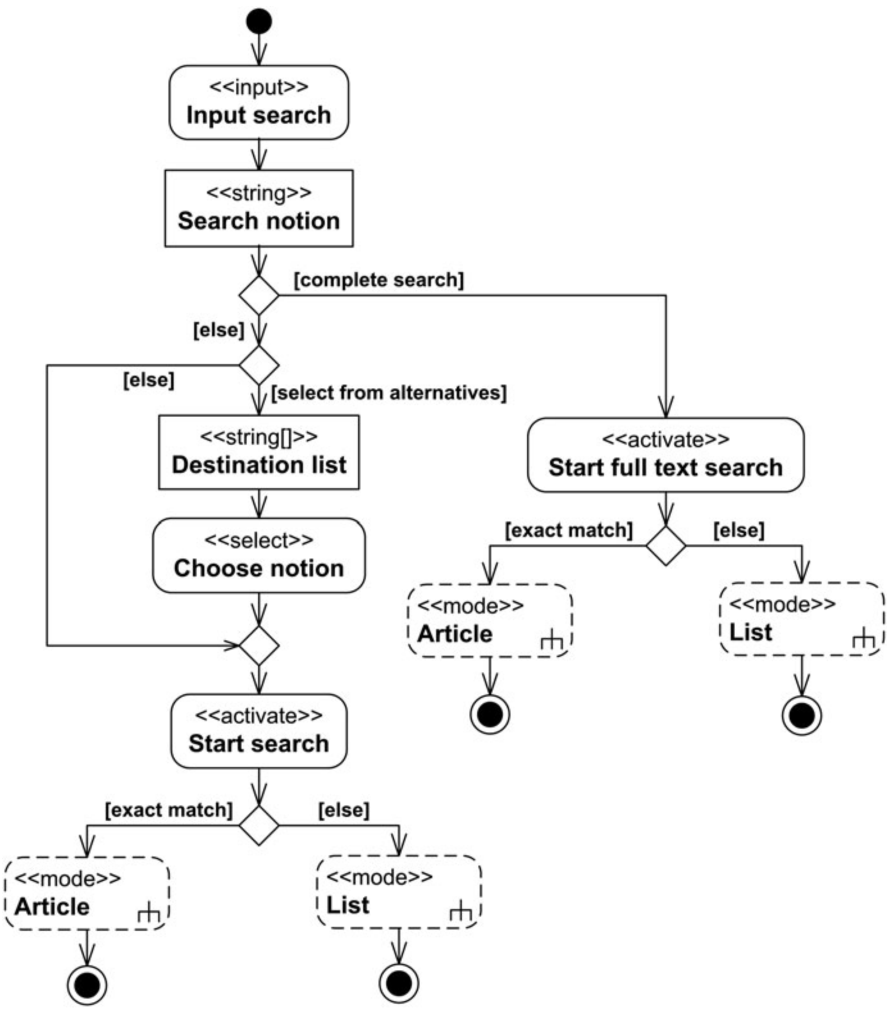


**Fig. 1** Example of a UML activity diagram

in diagrams by developers. HUTN provides short notations for modeling artifacts as objects, relations, attributes or methods. Until now, tool support such as the Epsilon-plugin [7] is very rare and a UML adaption for HUTN is still missing. Therefore, usage of HUTN needs the translation from UML to HUTN with the MOF meta-model.

For our evaluation, HUTN was adapted for the INAMOSYS task and presentation modeling with activity and class diagrams. The models were generated with the EMF tools for the Eclipse platform including Epsilon for the HUTN access. Listing 1 shows a part of the corresponding HUTN presentation for Fig. 1.

**Listing 1** Part of HUTN-notated task model

```
@Spec {
  metamodel "Task_Model" {
    nsUri: "Task_Model"
  }
}
package  {
  Activity "Submode_Search" {
    activity: Activity "Submode_Search"
    Rel1: Workflow "Workflow1" {
      Rel2: input "[Input search]" {
        name: "[Input search]"
      }, Structured Activity Node "<<Search>>[Search notion]" {
        name: "<<Search>>[Search notion]"
      }, activate "<<activate>>[start full text search]" {
        name: "<<activate>>[start full text search]"
      }
      ...
    }
  }
}
```

Model notation is semantic identical in UML and HUTN. The textual notation does not describe graphical layout as the size and position of symbols, boxes, arrows and lines. However, the power of modeling is not affected since layout is a non-semantical aspect of UML modeling.

## 3.2 Evaluation and Results

Evaluation method was a heuristic test by two modeling experts. The quality and functionality of the diagrams were tested with screen reader (JAWS 10.0) including the following issues:

- User can identify the metadata of the diagram (title, type, author etc.)
- User has orientation and overview during reading the diagram and navigation is possible
- Diagram elements can be identified
- User understands the meaning of the text elements
- User can manipulate the models

Table 1 summarizes some positive and negative results of the evaluation.

Generally, HUTN provides a good access to UML models. Since it has low redundant information, the user must know the syntax properly.

**Table 1** Evaluation summary

| | |
|---|---|
| + | Direct manipulation of UML diagrams |
| + | Simple and generic principles for notation |
| + | Short, well-readable notation |
| + | Avoidance of redundant information |
| – | Complex nesting of elements is hard to read |
| – | Closing of elements may be ambiguous |
| – | Additional data for automatic model transformation as ID attributes cause more workload for human reading |

## 4 Conclusions and Outlook

In the presented concept, HUTN was used for the text-based presentation of UML activity and class diagrams and evaluated with screen readers. The results have shown that HUTN presentation is much shorter and easier to understand than earlier approaches based e. g. on the XML-conform XMI format. An accessible presentation and manipulation of UML models is possible. Nevertheless, HUTN has some weaknesses regarding the orientation in long documents or the deep nesting of elements. HUTN files are presentable with standard assistive technologies as Braille devices or screen readers. Until now, tool support is very rare and does not corresponding with the advantages for people with low vision. Due to the used tools, the model support is restricted to a subset of MOF. Further work is necessary to provide a complete HUTN-support for UML models. Even, the publicity is not accord with the chances for inclusion of people with low vision.

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# Early Accessibility Evaluation in Web Application Development

**Helmut Vieritz, Daniel Schilberg and Sabina Jeschke**

**Abstract** Existing accessibility guidelines are mainly focused on runtime behavior and do not provide recommendations and evaluation for conceptual design of Web applications. Our approach aims to support more abstract principles for analysis and design of accessible Web applications. Combined with a prototype evaluation, it provides early integration of accessibility requirements into the process of Web application development.

The approach is based on a model-driven user interface design method. Analysis of tasks and workflow is used to design a prototype which is evaluated with a simple screening technique to get fast and efficient results on selected accessibility requirements.

The longtime objective of this work is a general concept for software development which bridges the gap between user requirements and developers needs in the field of accessibility.

**Keywords** Accessibility · Evaluation · Web Development · User-Centered Design

## 1 Background

Accessibility of Web-based user interfaces (UI) is an important research topic on human-computer interaction (HCI). Accessibility and usability [1] have as non-functional requirements an important impact on software architecture and design. As other non-functional needs e. g. scalability and reliability, they have to be considered early in the design process to realize them successfully. Common existing accessibility recommendations as the Web Content Accessibility Guidelines (WCAG 2.0 [2]) of the World Wide Web Consortium (W3C) are focused on runtime behavior and require implementation to be evaluated. They do not match the needs in early development phases as software analysis and design.

Typically, prototyping or mockups help to overcome this lack of rules in analysis and design. Use case description provides the required information regarding user

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task objectives and activities. Based on task analysis, user-centered design (UCD) allows focusing on UI interaction. Here, an analysis and modeling approach is described to implement and evaluate a part of the WCAG 2.0 recommendations in early UI prototypes. Research questions are:

1. How can accessibility requirements be integrated early in analysis and design of Web application development?
2. What kind of technique is useful to evaluate the prototypes regarding accessibility?
3. What kind of technology can be used to design and implement accessible UI prototypes?

The next section gives an overview regarding the related research. The overall concept of the approach and the research questions are presented in Sect. 3. A case study in Sect. 4 details the approach and finally in Sect. 5, the conclusions and the outlook complete the discussion.

## 2 Related Research

User-centered design (UCD) is a common method to ameliorate the usability. Accessibility in UCD is described by Henry [3] focusing on integration of users with disabilities in analysis, design and evaluation. Early usability evaluation is discussed in [4]. The approach is based on the model-driven architecture (MDA) and a usability framework. The specifics of accessibility are not focused.

Approaches for Model-driven Design (MDD) in UI development are User Interface Markup Language (UIML) [5], User Interface Description Language (UIDL) [6], User Interface Extensible Markup Language (UsiXML) [7], useML [8], Unified Modeling Language for Interactive Applications (UMLi) [9], Task Modeling Language (TaskML) [10] and Dialog Modeling Language (DiaMODL) [10]. Three UI models are known as essential [11] – the task, dialog and (abstract) presentation model.

Only few publications address the integration of accessibility in MDD of UIs. The Dante project [12] 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. [13, 14]. As well, more details of our UI modeling process can be found in [13, 14].

## 3 The Approach

In short, accessibility means that all required information is perceivable, operable, understandable and robust (usable with different UI technologies) [2]. Information is required if the user needs it to accomplished his or her working tasks. Thus, analysis

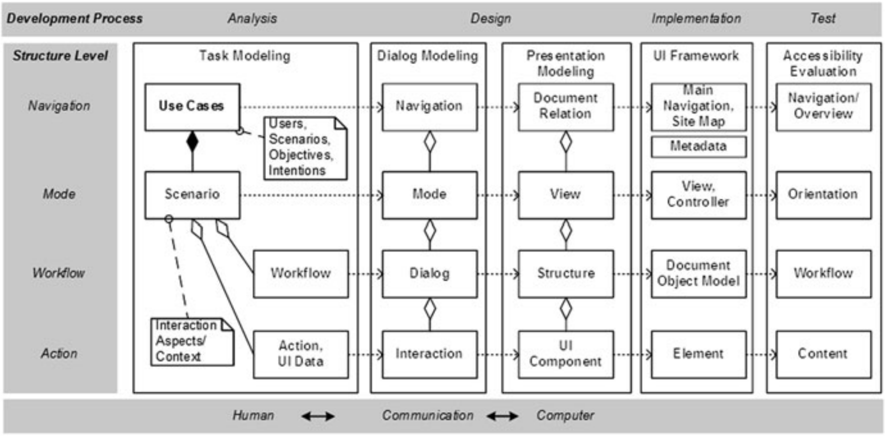


**Fig. 1** Development process at a glance

and identification of workflow-related information is the key to early accessibility integration. Analysis starts with use case description including possible scenarios of HCI. Important information is the identification and temporal order of main activities at the one side and of user actions and workflow at the other. Complex tasks need different modes of HCI and navigation between them. Modes are consistent subsets of user actions e. g. edit the shipping address in online shops [4]. They are related to a user main activity respectively scenario – e. g. carry out online purchases.

The presented approach is based on a general UI modeling concept which is discussed in former publications [13, 14]. The objective of this concept is the integration of accessibility requirements during the development process of an e. g. Web application. Figure 1 gives an overview. The concept separates four different structure levels. Two are the (macro)-levels of modes and the change of modes (navigation). A mode is particular context of HCI (e. g. a single Web site) or a view in a desktop application (e. g. an editor or a file browser) [15]. The other two are the basic user actions and their temporal order (workflow). For analysis and design, three essential UI models [11] are required – the task model, the dialog model and the presentation model. The task model describes user's point of view on the HCI and represents the more technology-independent part of all UI models. The presentation model describes the (abstract) structure and behavior of the UI technology and represents the system view on the HCI. The dialog model combines both worlds in one view and specifies the interaction by describing the information interchange between user and system.

In this publication, the focus is set on earliest accessibility integration in analysis, design and implementation of the two macro-level navigation and modes. Based on task analysis and the modeling of HCI modes, a simple UI prototype can be implemented and evaluated for some accessibility criteria (first research question). Related aspects include user's orientation, over-view and navigation in HCI with

**Table 1** Relevant WCAG 2.0 guidelines

| No. | Guideline |
|---|---|
| 1.3.3. | Sensory characteristics |
| 2.1.1. | Keyboard |
| 2.1.2. | No keyboard trap |
| 2.4.3. | Focus order |
| 2.4.4. | Link purpose |
| 2.4.5. | Multiple ways |
| 2.4.6. | Headings and labels |
| 2.4.7. | Focus visible |
| 2.4.8. | Location |
| 3.2.3. | Consisted navigation |

Assistive Technology (AT) e. g. Screen readers. Affected criteria of the WCAG [2] are given in Table 1. More abstract accessibility requirements were derived from guidelines:

4. Clearly structured activities – a particular Web site is focused on only one main activity which can be identified by the title-element. Main activities are mapped one by one to a UI mode.
5. Serial order of modes corresponds with user's expectation to support assistive technology as screen readers etc.
6. Navigation is accessible and corresponds with user's mental representation.

To answer the second research question, a simple and easy evaluation method is the screening technique. Most screening techniques are based on interaction with the UI with limited sensory or physical abilities (see [3] for more details) e. g. low vision glasses. Instead of the monitor the software designer can use a screen reader to interact with the application. Tests can include adaptive strategies or assistive technologies. Screening tests are best-suited during early design.

For implementation, Web application frameworks were evaluated. Regarding the third question, Java Server Faces (JSF) was chosen since it allows the easy implementation of the navigation model. Figure 2 shows the seven steps of the approach in an overview. In the next section, the process is discussed in detail and tested in a case study.

## 4 Case Study

The approach was used to design a prototypical user-centered UI for a finite element (FE) integration system in virtual production. In complex processes different physical simulations are needed to analyze and parameterize the whole process. Information

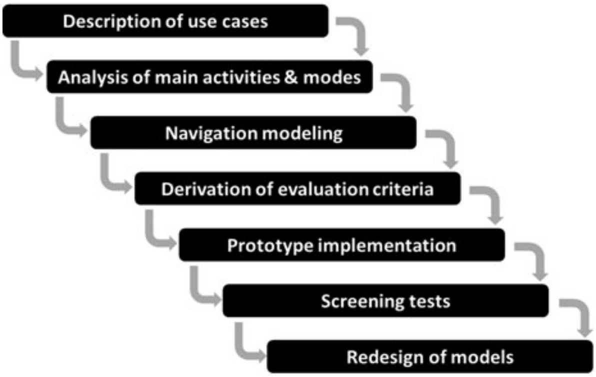


**Fig. 2** Process overview

integration provides inter-simulation communication to combine particular physical processes.

The usage of the system was described by the customer with a use case diagram (Fig. 3) and an additional description of activities. Typical use cases of the customer were login to the system, start an information integration or extraction, select, load and download files.

Based on scenarios, the related activities and actions were analyzed and modeled within activity diagrams. The first step was to identify user main activities, to group similar activities and to model the use modes of the UI. The grouping of similar activities avoids the design of use modes which are almost identical. This step reduces the number of modes. Fewer modes simplify the UI and reduce learning efforts. Alternatively, structure layering techniques etc. can be used for customers without technical background when they e. g. are not familiar with UML activity diagrams. Evaluation criteria are derived from use case analysis including:

7. Can the main activities be recognized by using a screen reader?
8. Is the navigation accessible? Are navigation options and targets always clear?
9. Is the navigation from site to site adequate to the expected work-flow?

The temporal arrangement of modes is described in the navigation model (Fig. 4). The model is notated as a UML activity diagram. Modes and sub-modes are assigned with UML stereotypes.

For the implementation of the navigation model, Java Server Faces (JSF) was chosen. It supports the easy model-to-text transformation into the faces-config.xml file which describes the application navigation. Information from the model was used to implement the particular JSF views which represent the sites of the Web application. The prototype does not contain a particular navigation system. Thus, the changes from site to site were implemented as hyperlinks. Additionally, the sites contain some meta-information as the title which corresponds to the mode name in the navigation model.

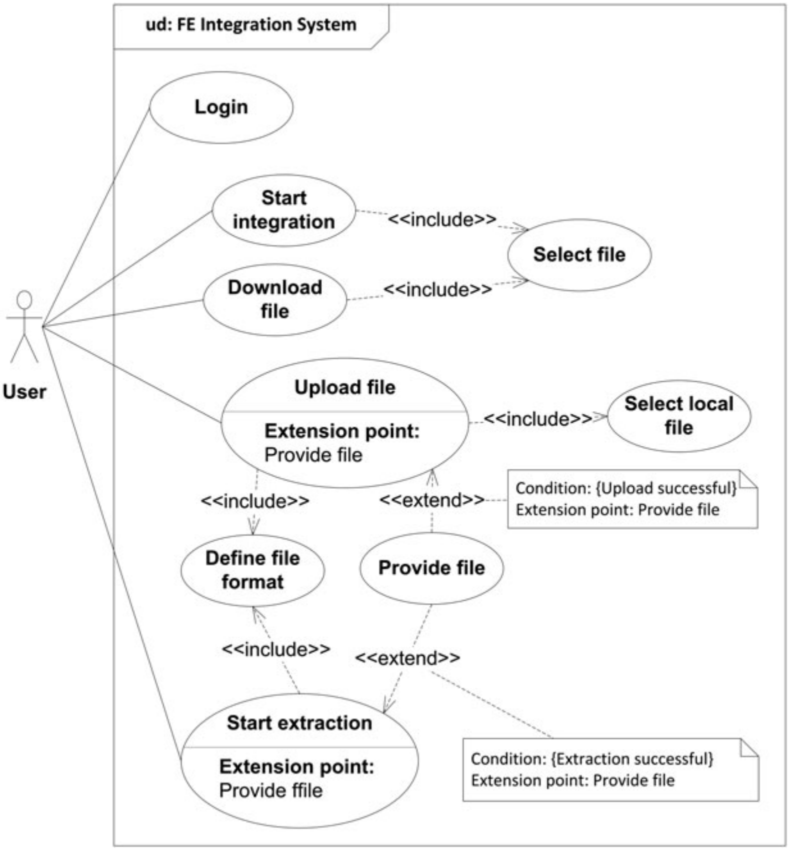


**Fig. 3** Use cases for an information integration system

A screening test with the simple prototype was done by three developers with screen readers. Since the developers were not familiar with the AT, a longer warm-up was necessary. The test has shown that:

- User clearly identify main activity
- User identify next expected activity
- Last activity was sometimes not clear for the user
- Users could evaluate the accessibility to main navigation, home mode etc.
- User overlooks the main steps of workflow within the application

Additionally, the mentioned WCAG criteria were checked. For some criteria (2.4.3, 2.4.7, 3.2.3) a complete testing was possible. Test results were used to fix errors in the prototype. Complete testing for the other criteria (1.3.3, 2.1.1, 2.1.2, 2.4.4, 2.4.5, 2.4.6 and 2.4.8) requires additionally the implementation of content. Therefore, testing had to be finished in later development phases. It was remarked by the test persons that the short-time feedback of the test helps to understand better the accessibility requirements.

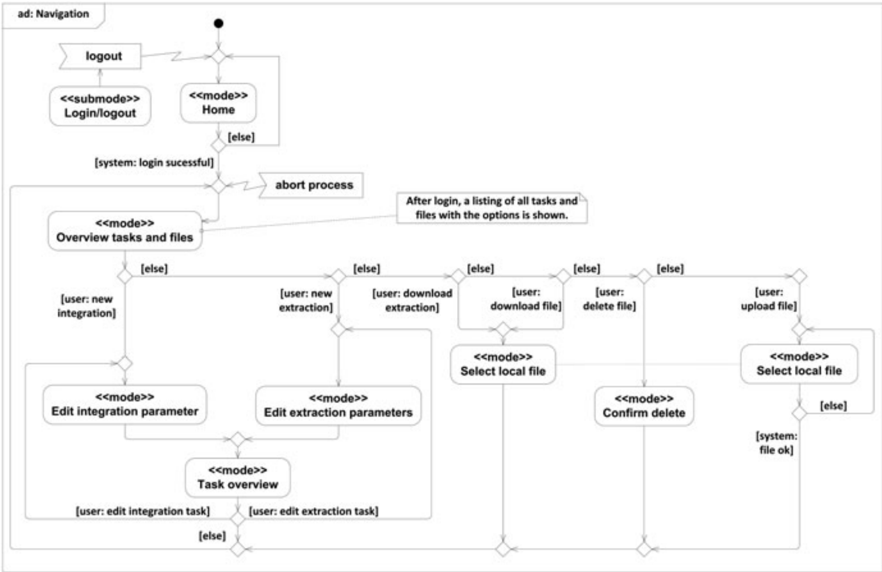


**Fig. 4** Navigation model for an information integration system

# 5 Conclusions

The presented concept evaluates early accessibility evaluation in Web application design and development. Accessibility requirements regarding navigation, orientation and overview are combined with UCD and MDD. The concept is based on task analysis and modeling. The case study has shown that a limited early accessibility evaluation is possible. WCAG testing can be finished for some criteria. The majority of criteria is content-related and need more implementation. Even, some general aspects as overview, orientation and (macro) navigation can be evaluated early. Limitations of the approach are:

- Only subset of accessibility criteria is testable
- Evaluation focused on AT for visual impairments
- Need for more comprehensive evaluation

Further research would be necessary to test more criteria related to others impairments and disabilities e. g. a systematic approach based on the International Classification of Functioning, Disability and Health (ICF) of the World Health Organization (WHO). Systematic accessibility guidelines for the design and conception of Web applications (or software in general) are still not available. They are required for a holistic integration of accessibility in development processes. Last but not least, the approach is focused on early accessibility integration. Further work is necessary to cover the whole development process in a systematic way.

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# A New Approach for 3D Edge Extraction by Fusing Point Clouds and Digital Images

**Ying Wang, Daniel Ewert, Daniel Schilberg and Sabina Jeschke**

**Abstract** Edges are crucial features for object segmentation and classification in both image and point cloud processing. Though many research efforts have been made in edge extraction and enhancement in both areas, their applications are limited respectively owing to their own technical properties. This paper presents a new approach to integrating the edge pixels in the 2D image into boundary data in the 3D point cloud by establishing the mapping relationship between these two types of data to represent the 3D edge features of the object. The 3D edge extraction – based on the adoption of Microsoft Kinect as a 3D sensor - involves the following three steps: first, the generation of a range image from the point cloud of the object, second the edge extraction in the range image and edge extraction in the digital image, and finally edge data integration by referring to the correspondence map between point cloud data and image pixels.

**Keywords** Edge Extraction · Data Fusion · Digital Images · Point Cloud

## 1 Introduction

Edges are primitive features of an object that are widely used in image classification and analysis systems to outline the boundaries and features of objects [1]. In digital images, an edge is a local change or discontinuity in image luminance. There are two basic approaches to image edge detection [2]:

- The thresholding method: discontinuities in an image attribute are enhanced or accentuated by some spatial operator. If the enhanced discontinuity is sufficiently larger than some threshold level, then an edge is deemed present.
- The edge fitting method: fitting of an ideal edge replica, a two dimensional ramp or step function, to the image some region. If the fit is close, an edge is judged present.

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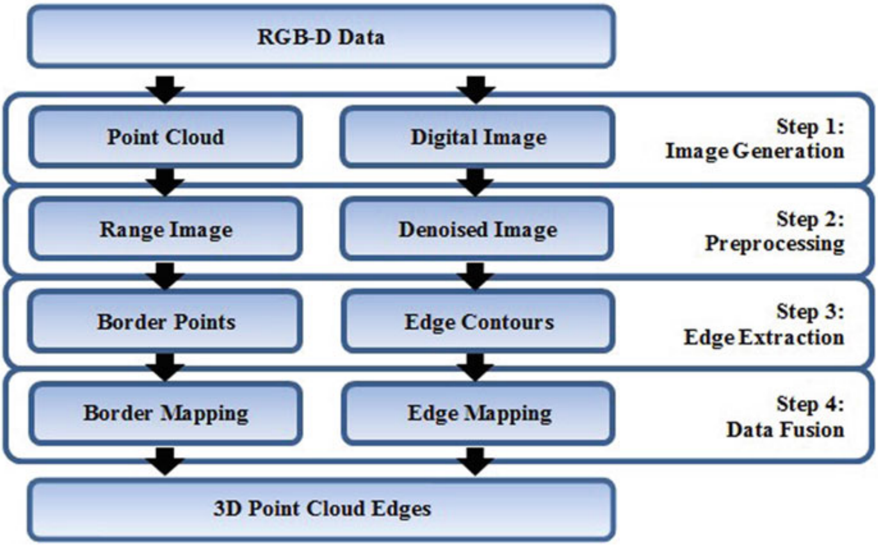


**Fig. 1** Proposed approach

Edge detection forms an important requirement for feature extraction in point clouds [3, 4], which in turn can be divided into two main categories [5]:

- Mesh-based feature extraction: implementing a threshold test which identifies the points as edge candidates if their normal and those of their neighboring points are above the threshold. However, the implementation of such detection techniques is not straightforward, since in most cases, normals and connectivity are not available in point data sets and it is difficult to implement reconstruction.
- Point-based extraction: using PCA (principal component analysis) and segments the points into groups based on the normal variation in local neighborhoods.

In this paper, a new edge extraction approach is proposed and implemented, based on the utilization of the thresholding method and point-based method for edge extraction respectively in a 3D point cloud and a digital image and the fusion of the edge data:

- On the point cloud part, a range image is generated from the point cloud data and as a preparation work, the raw point cloud data is de-noised by a $5 \times 5$ Gaussian filter [6] to eliminate the noise effects and then edge extraction operation is performed on the range image by using the point sample-based method (step 1 & 2 in Fig. 1).
- On the digital image processing part, edge extraction is applied on the digital image using the Canny algorithm after preprocessing of the raw image data (step 3 in Fig. 1).
- Finally, edge pixels in the image are integrated into the point cloud by mapping them into the corresponding locations in the point cloud data array (step 4 in Fig. 1).

The remainder of the paper is organized as follows: Sect. 2 presents the main approaches to edge extraction (step 3 in Fig. 1) and mechanisms for data fusion of point cloud and 2D image data (step 4 in Fig. 1); Sect. 3 summarizes the contribution of this work and plans about future work.

# 2 Approach

## *2.1 Edge Extraction in Digital Image*

This paper applies the Canny edge detection algorithm [7, 8] for edge extraction in digital image, which is known as the optimal and the most commonly used edge detector among all the other image processing algorithms. As the Canny edge detector is susceptible to noises, a 5×5 Gaussian filter ($\sigma = 1.4$) (Eq. 1) is used to convolve with the raw image to eliminate noise effects.

$$B = \frac{1}{159}\begin{pmatrix} 2 & 4 & 5 & 4 & 2 \\ 4 & 9 & 12 & 9 & 4 \\ 5 & 12 & 15 & 12 & 5 \\ 4 & 9 & 12 & 9 & 4 \\ 2 & 4 & 5 & 4 & 2 \end{pmatrix} * A. \tag{1}$$

In the Canny algorithm, the first derivatives are computed in x and y and then combined into four directional derivatives. The points where these directional derivatives are local maxima are then candidates to be assembled into edges. The Sobel filter (Eq. 2) is applied in x and y direction on the image and the gradient strength and direction are calculated by Eq. 3 in order to round edges which could lie in any direction to four main direction: horizontal, vertical and diagonal (0, 45, 90 and135°).

$$G_x = \begin{pmatrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{pmatrix}, \text{ and } G_y = \begin{pmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ +1 & +2 & +1 \end{pmatrix}. \tag{2}$$

$$G = \sqrt{G_x^2 + G_y^2}, \text{ and } \theta = \arctan\left(\frac{G_y}{G_x}\right). \tag{3}$$

The non-maximal suppression operations are performed with the known gradients to keep those points with highest gradient magnitude and filter out the others. The Canny algorithm assembles the individual edge candidate pixels into contours which are formed by applying a hysteresis threshold on each pixel. Therefore, a pixel is accepted as an edge pixel if it has a gradient larger than the upper threshold; rejected,

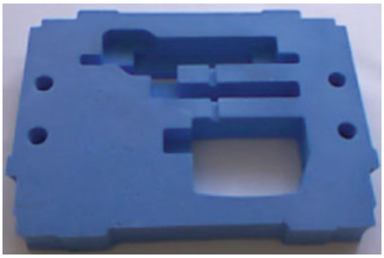

**Fig. 2** Digital image

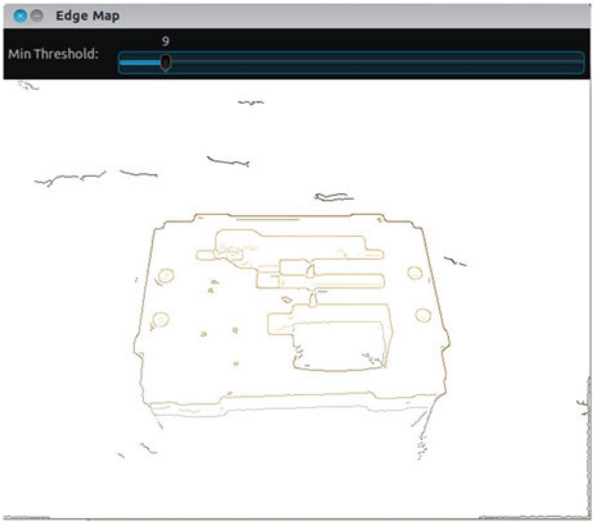


**Fig. 3** Lower threshold = 9

if smaller than the lower threshold. If the pixel's gradient is between the thresholds, then it will be accepted only if it is connected to a pixel that is above the high threshold. The object with a multitude of edges is shown in a digital image (Fig. 2) and the results of the Canny edge detection at different lower thresholds (9 and 24) are shown in Figs. 3 and 4. Obviously, the main physical features of the object are outlined with satisfaction.

## 2.2 *Edge Extraction in Point Clouds*

The adoption of Microsoft Kinect as a 3D sensor enables the access to both 3D point cloud and digital image of the object at the same time, attributed to its depth camera and RGB camera. In this paper, the point cloud of the object is first saved as PCD (point cloud data) format and is also used to convert to digital image format. A range image is generated from the object point cloud data, because range images that are easily accessible from arbitrary 3D point clouds explicitly consider the edges of

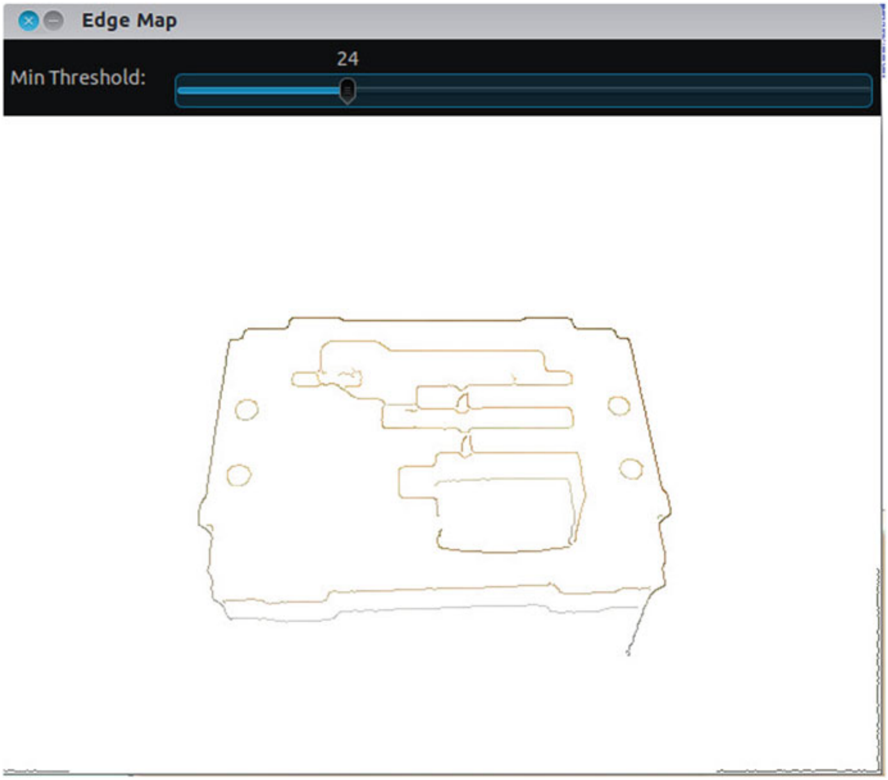


**Fig. 4** Lower threshold = 24

the objects identified by transitions from foreground to background with a reliable performance in object recognition.

The algorithm for border extraction described in [9] and [10] is applied to extract the outermost borders of the object as well as shadow borders, which are points in the background adjoining occlusions, and veil points, which are interpolated points between the obstacle border and the shadow border.

1. Suppose a point $p_i$ lies in the middle of a square of size $s = 5$ all neighboring points $\{n_1, \ldots, n_{s^2}\}$ in the range image. Their 3D distances $\{d_0, \ldots, d_{s^2}\}$ to $p_i$ are ranked in increasing order to get $\{d'_0, \ldots, d'_{s^2}\}$. Assuming that at least a certain number $M = \left(\frac{(s+1)^2}{2}\right) = 9$ of the points lie on the same surface as $p_i$, we select $\delta = d'_M$ as a typical distance to $p_i - s$ neighbors, which do not include points beyond a border.
2. Calculate the average 3D position of some neighbors of the point $p_{xy}$ on the right as Eq. 4

$$p_r = \frac{1}{m_p} \sum_{i=1}^{m_p} p_{(x+i)y}. \tag{4}$$

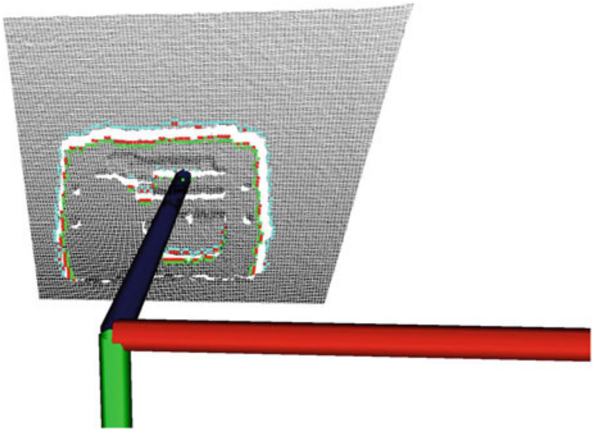

**Fig. 5** Edge detection in the point cloud

Where $p_r$ is the neighboring point on the right and $m_p$ is the number of points.

3. Based on $\delta$ and 3D distance $d_r = ||p_{xy} - p_r||$, a score value $s_r$ in [0,1), which stands for more probable border with a bigger value, is calculated by Eq. 5

$$s_r = max\left(0, 1 - \frac{\delta}{d_r}\right). \tag{5}$$

4. Apply the smooth operation to obtain continuous border and to eliminate noises.
5. Determine a given point $p_{xy}$ is in the foreground or background by the criteria: $p_{xy} - p_r > 0$ indicates $p_{xy}$ belongs to shadow border, otherwise it is on the obstacle border.
6. If $s_r$ is above a threshold and if it is a maximum regarding $p_{(x-1)y}$ and $p_{(x+1)y}$, $p_{xy}$ will be marked as an obstacle border, its counterpart from above as a shadow border, and all pixels in between as veil points.

The result of edge detection on the object point cloud is shown in Fig. 5, in which blue points are shadow borders, red points are veil points and green points are obstacle border. The camera coordinate system is also displayed in a way that red, green and blue axis respectively represent x, y and z axis, pointing to the positive directions.

## 2.3 Edge Data Fusion

The determination of point correspondences between the 3D point cloud and the 2D pixels is implemented by mapping the 2D image to the point cloud, so that the 3D coordinates to every pixel in the digital image are known. The main idea behind the edge data fusion in our work is to integrate edge data from 2D image to point clouds by relating the pixel location of edge contours in the 2D image to the corresponding position of the point cloud data array.

**Table 1** PCD format example

| PCD Format | | Comments |
|---|---|---|
| VERSION | .7 | The PCD file version |
| FIELDS | X Y Z rgb | The name of each dimension/field that a point can have |
| SIZE | 4 4 4 4 | The size of each dimension in bytes |
| TYPE | F F F F | The type of each dimension as a char |
| COUNT | 1 1 1 1 | How many elements does each dimension have |
| WIDTH | 640 | The width of the point cloud dataset in number of points |
| HEIGHT | 480 | The height of the point cloud dataset in the number of points |
| VIEWPOINT | 0 0 0 1 0 0 0 | An acquisition viewpoint for the points in the dataset |
| POINTS | 30720 | The total number of points in the cloud |
| DATA | ascii | The data type that the point cloud data is stored in |
| $P_0 \ldots P_{30719}$. | | Each point in a new line |

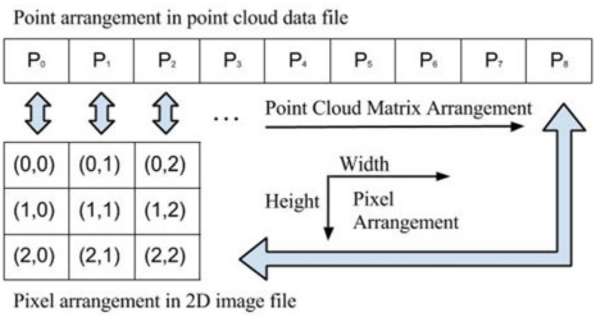


**Fig. 6** The correspondence map

As the point cloud obtained from RGB-D sensors of Kinect is already organized, the point cloud data are defined at various locations in XYZ coordinate system and arranged in an array in PCD file. The PCD format [10], complementing the existing formats for describing arbitrary polygons and point clouds acquired using laser scanners, supports n-D point cloud data storage and processing, as shown in Table 1.

Since the same indexes are used in point cloud data and 2D image when describing a view at the same viewpoint, the organized point cloud data corresponds to pixels in the digital image as shown in Fig. 6. Thus, mapping relationship can be established between the point cloud data and 2D image data, based on which edge contours extracted in digital image can be mapped to corresponding points in point cloud to obtain more features of object features with depth information. Finally, edges on the digital image are integrated into the original point cloud by finding out the correspondence of edge pixels in the point cloud from the established map, thus enlarge the 3D edge dataset.

# 3 Conclusion

This paper presents a new approach for 3D edge extraction through fusing the detected edges of the object in its point cloud and digital image, addressing the requirement of feature extraction in object segmentation and classification in vision processing. An easy and effective way of point cloud and image data fusion is proposed, owing to the correspondence between pixel locations and the location of point cloud data array. In conclusion, the proposed edge extraction approach is able to extract object edges in its point cloud and 2D image and to extend the edge dataset in 3D point cloud, achieving complementary effects of edge extraction from either dataset. For future research, more work will be done in evaluating and optimizing the performance of our edge extraction approach by performing experiments on a good variety of featured objects in three aspects:

- Precision: detecting object edges with a complete coverage.
- Accuracy: obtaining the edge position information with high exactness.
- Rapidity: extracting edges with a high computing speed.

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# Edge Extraction by Merging the 3D Point Cloud and 2D Image Data

**Ying Wang, Daniel Ewert, Daniel Schilberg and Sabina Jeschke**

**Abstract** Edges provide important visual information by corresponding to discontinuities in the physical, photometrical and geometrical properties of scene objects, such as significant variations in the reflectance, illumination, orientation and depth of scene surfaces. The significance has drawn many people to work on the detection and extraction of edge features. The characteristics of 3D point clouds and 2D digital images are thought to be complementary, so the combined interpretation of objects with point clouds and image data is a promising approach to describe an object in computer vision area. However, the prerequisite for different levels of integrated data interpretation is the geometric referencing between the 3D point cloud and 2D image data, and a precondition for geometric referencing lies in the extraction of the corresponding features.

Addressing the wide-ranged applications of edge detection in object recognition, image segmentation and pose identification, this paper presents a novel approach to extract 3D edges. The main idea is combining the edge data from a point cloud of an object and its corresponding digital images. Our approach is aimed to make use of the advantages of both edge processing and analysis of point clouds and image processing to represent the edge characteristics in 3D with increased accuracy.

On the 2D image processing part, an edge extraction is applied on the image by using the Canny edge detection algorithm after the raw image data pre-processing. An easily-operating pixel data mapping mechanism is proposed in our work for corresponding 2D image pixels with 3D point cloud pixels. By referring to the correspondence map, 2D edge data are merged into 3D point cloud. On the point cloud part, the border extracting operator is performed on the range image. As a preparation work, the raw point cloud data are used to generate a range image. Edge points in the range image, points with range, are converted to 3D point type with the application of the point cloud library (PCL) to define the edges in the 3D point cloud.

**Keywords** Edge Detection · Data Fusion · 2D Digital Images · 3D Point Clouds

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## 1 Introduction

Feature detection has its widely-spread use in a good variety of domains, ranging from quality measurement [1], monitoring of manufacturing processes [2], medical applications to prototyping and design. Those research and manufacturing purposes can be better served when those features are known with accuracy and adequacy. To better describe an object visually, it is ideal to take the combined advantages of edge extraction approaches in both 2D and 3D vision processing. Meanwhile, they can also offset each other's weak points in some ways, e. g. poor lighting effects on 2D image can be largely reduced by the assistance of 3D edges because 3D vision data tell objects from background with depth information.

In 2D images, physical edges are represented in the image by changes in the intensity function because image intensity is often proportional to scene radiance. In order to provide significant information about the 2D image, derivatives are computed by the edge detector which accepts digitized images as input and produces an edge map as output, which includes explicit information about the position, orientation, scale and strength of edges. However, since image deviates are sensitive to noise, smoothing operations [3], in most cases, are required to process the images aiming at reducing noise and regularizing the numerical differentiation, thus ensuring robust edge detection.

The 3D point cloud data acquired by 3D visual sensors, such as laser scanners, provide the geometric information of the sampling points on the surfaces of physical objects. The geometric features in 3D point cloud data, such as ridges and corners which are composed of the geometric discontinuities, contain the important feature information of physical objects [4]. The edge extractor attempts to detect discontinuities in the surfaces that form the closed boundaries of components in the point data.

This paper introduces and validates a novel approach of 3D edge extraction by fusing detected edges from both 3D point cloud data and 2D digital image data into object point cloud data, notably supplementing the dataset of 3D edge points. A range image is generated from the 3D point cloud of the object to define the borders of the object by transitions from foreground to background, and then the borders of the range image are mapped into the point cloud. Canny edge detector [5, 6] is applied to extract edge features from the digital image which is captured at the same time that PCD (point cloud data) are saved. The correspondences between point cloud and digital image pixels are established for merging the edge pixel data into point cloud, thus obtaining edge maps with 3D information.

The paper is organized as follows: Sect. 2 presents a brief review of the recent literature about edge extraction approaches respectively in 2D digital images and 3D point clouds. The workflow and main algorithms of our proposed 2D-3D edge merging approach are presented and discussed in Sect. 3. An analysis is made in Sect. 4 on our preliminary experimental results to validate the feasibility of the proposed approach. Section 5 summarizes the outcomes of this work and plans about future work.

## 2 Related Work

### 2.1 2D Edge Extraction

A variety of edge operators have been developed in the 2D image processing area, which can be categorized into three main classes: linear method, non-linear method and the best-fit method [7]. A common linear edge enhancement method is differencing. The discrete approximation of the first order derivative in a given direction is one of the simplest methods. Sharifi [8] categorizes the most frequently used edge detectors based on the behavioral study of the edges into five groups. The gradient edge detectors [3, 9] contain classical operators and uses first directional derivative operation. The zero crossing [10] applies second derivatives and includes Laplacian operator and second directional derivatives. The Laplacian of Gaussian [10, 11] adopts the combined Gaussian filtering with the Laplacian. The Gaussian edge detector is symmetric along the edge and reduces the noise by smoothing the image and the colored edge detector [12] can be divided to three classifications: output fusion methods, multi-dimensional gradient methods and vector methods.

All these edge detectors have their superior performance in some specific aspects, which accounts for their popularity in feature extraction in image processing. Excelling in edge identification and orientation, classical operators, zero crossing operators and Laplacian of Gaussian operators are sensitive to noise and have poor performance in accuracy levels. Gaussian and colored edge detectors, with the prices of high complexity and low computation speed, are accurate and efficient in edge recognition with the presence of noises. Among all these popular edge extraction methods, second derivative operators, such as ISEF and Canny, exhibit better performance in processing noisy images, but meanwhile take up more computation time owing to smoothing the image with a Gaussian function first and then computing the gradient.

As the performance of ISEF and Canny edge detector highly depend on the selection of parameters and particular images, no fair judgments can be made regarding the superiority between these two methods. Canny edge detector is applied on digital images in our work to obtain the object edge pixel data by first reducing noise, then computing the gradient, performing the non-maximum suppression and the hysteresis thresholding, securing the accuracy while avoiding the noise effect which is a major challenge in image processing.

### 2.2 3D Edge Extraction

The *3D edge extraction* in this paper specifically refers edge extraction in 3D point clouds. In the point cloud processing area, the existing feature detection methods can be classified into two main groups: polygonal-based methods [13, 14] and point-based methods [15, 16]. The former method generates a set of edges by using the connectivity information and normal associated with the underlying polygonal meshes. Hubeli and Gross [17] define a set of edges by performing a normal-based classification in the image and refine the edges with a thinning process to generate sharpened feature lines. Anisotropic filtering is employed to discrete differential geometry properties of third-order derivatives of the surface mesh by Hildebrandt et al. [18]. Watanabe and Belyaev [19] compute approximation of the mean curvatures and Gaussian curvatures with the application of discrete differential geometry operators. Discrete meshes are commonly used in these methods to obtain the differential geometry, though it is not an optimal choice due to its complexity. Most of these mesh-based methods also require the insertion of additional vertices on the edges and the projection of the vertices to the intersection of planes fitting to the surrounding surfaces.

The point-based methods analyze each point at its neighbor points via PCA (principal component analysis) and the eigenvalues of the correlation matrix are used to determine the probability of the point belonging to an edge. To evaluate the potential of the target point to be a feature point, Pauly et al. [16] perform a covariance analysis of the distance-driven local neighborhoods. With the varying radius of the neighborhoods, they design a multi-resolution framework which is able to handle noisy input data. The covariance analysis is also applied in the work of Gumhold et al. [15], together with a Riemann graph over the local neighborhoods, to compute the scores that determine which catalogue the point fall to: potential creases, boundaries or corners. Demarsin et al. [20] develop a region growing method that extracts clusters from the point cloud and outline the regions of sharp features to define closed feature borders. The major problem of these point based methods is the lack of knowledge concerning normal and connectivity information. This makes feature detection a more challenging task in the point-based methods than that in mesh based methods.

Besides all the above mentioned approaches, Steder et al. [21] present a novel interest keypoint extraction method that operates on range images generated from arbitrary 3D point clouds. The range image is widely recognized as a 2.5D image that explicitly considers the borders of the objects identified by transitions from foreground to background. By using the change in the distance between neighboring points as a border indicator, every image point is checked at its local neighborhood:

- adopting a heuristic to determine the 3D distance to neighboring points that are within the range defined by a border;
- calculating a score of the possibility that this point belongs to a border by the maximum 3D distance obtained from the last step;
- deciding on the type of the border that this point falls into by a *Border Criteria*;
- performing non-maximum suppression to locate the border in the image.

In our work, edge extraction in point cloud data is implemented by performing the method proposed in [21] on the range image. A range image is generated from the object point cloud data. Then the edges in the range image are mapped into the original point cloud to form an edge map.

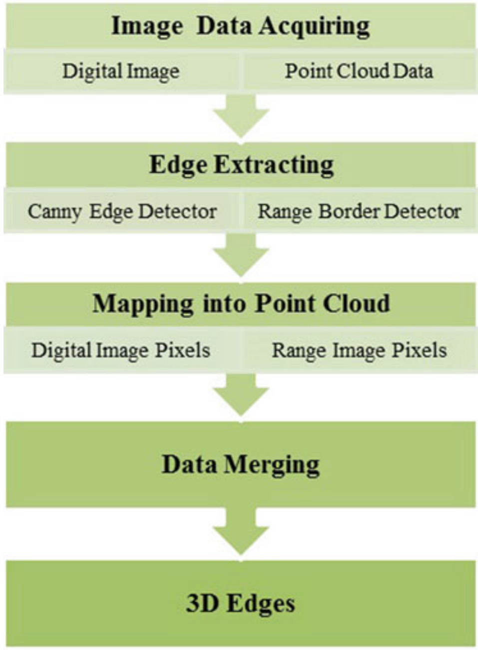



**Fig. 1** Workflow

# 3 2D-3D Edge Merging Algorithm

In this section, an illustration will be given regarding the workflow for our 2D-3D edge merging algorithm and explanations will be made on the main algorithms for 2D and 3D image pre-processing and edge detection, pixel mapping and data fusion from both 2D images and range images into the point cloud data (Fig. 1).

## *3.1 Workflow*

Four main steps contribute to the identification and positioning of the edges in the point cloud, respectively namely: *Image Data Acquiring*, *Edge Extracting*, *Mapping into Point Cloud*, *Data Merging* and forming *3D Edges*.

*Image Data Acquiring*: the digital image and point cloud data of the object are captured simultaneously at a certain viewpoint by a 3D Sensor, which is able to produce a RGB image with its color sensor and meanwhile generate a point cloud with its IR emitter and IR depth sensor.

*Edge Extracting*: this will be carried out on both 2D digital image data and 3D point cloud data respectively by Canny edge detector and border detector on the range image which is generated from the point cloud data. In both detectors, preprocessing functions are implemented for better interpreting the object visually and extracting the sharp edge features by smoothing the vision data.

*Mapping into Point Cloud*: as the point in range image represents Euclidean XYZ coordinates, padded with an extra range float, the correspondence can be easily established between point cloud data and range image data, which is the main theory behind mapping range image pixels to point cloud data. Likewise, mapping edge pixels in digital image into point cloud is validated to be feasible since they share identical indexes for their pixels.

*Data Merging*: edges extracted from both data sources are mapped to the corresponding point cloud pixels, thus entitling the point cloud data with known 3D edge features.

*3D Edges*: edges features of the object together with 3D space information are characterized by edge pixels in point cloud.

## *3.2 Detection Algorithm Overview*

### 3.2.1 Canny Edge Detector

Canny edge detector is one of the most commonly used processing tools, detecting edges in a reliable and robust way. It is a multi-step process described as follows, which can be implemented as a sequence of filters.

**Algorithm 1 (Canny Edge Detector)**

1. Preparation: *converting the RGB image to grayscale for processing*.
2. Smoothing: *applying a* $5\times5$ *Gaussian filter* [22] ($\sigma \approx 1.4$) *on the image data to suppress noise effects, without damaging the true edges*.
3. Computing gradient magnitudes and angles: *applying the Sobel filter* [5] *to compute the derivatives* ($D_x(x, y)$ *and* $D_y(x, y)$) *of the image in the x and y directions at each pixel, rounding the angles into* 0, 45, 90 *and* 135°.
4. Enhancement: *applying the non-maximum suppression algorithm to keep only those pixels on an edge with the highest gradient magnitude and exclude all the others, in order to enhance the quality of the edges in the image (sharpening the edge features)*.
5. Hysteresis Thresholding [5]: *adpoting two thresholds (thigh and tlow) to examine pixels at their gradient magnitudes, in order to avoid the problem of generating disconnected edges caused by simply using one single value as thresholding. Only the pixels whose gradient magnitudes are no larger than the high thresholding and also no smaller than the low thresholding are kept to form a continuous edge*.

In our work, extraction experiments are carried out on the object as shown in Fig. 2. Figures 3, 4 and 5 are the results of edge extraction on the object with a high thresholding at 100 and low thresholdings respectively at 5, 24 and 40. Obviously, the

**Fig. 2** Digital image

**Fig. 3** Edge map with $t_{low} = 5$

**Fig. 4** Edge map with $t_{low} = 24$

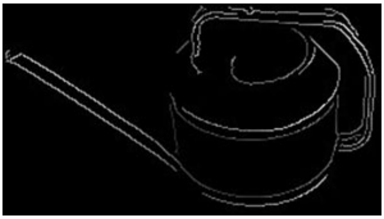


**Fig. 5** Edge map with $t_{low} = 40$

Canny edge detector is able to not only extract the main edge features of the object from its 2D image data, but also to ensure the completion and continuousness of those edges, when the low and high thresholds are properly selected.

### 3.2.2 Range Border Detector

The range border detector is applied on the range image generated from the object's 3D point cloud to define the borders of the object by transitions from foreground

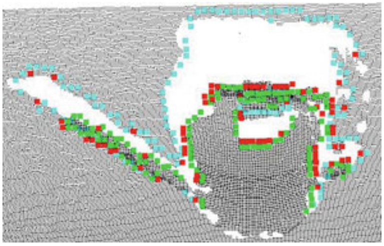


**Fig. 6** Border detection of range image

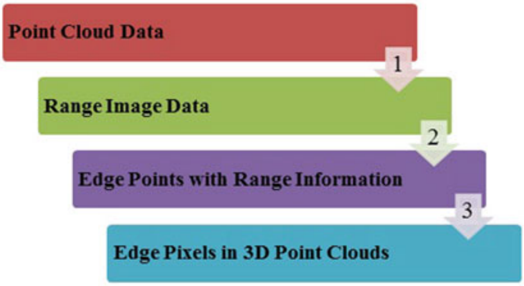
to background. Reference [21], propose that the change in the distance between neighboring points is the most significant indicator, which is also very robust against noise and changes in resolution, among all the other indicators for edge detection, such as acute impact angles and changes of the normals. In a range image, there are three kinds of points that are of our research interest: object borders, which are the outermost visible points still belonging to an object, shadow borders, which are points in the background that adjoin occlusions, and veil points, interpolated points between the obstacle border and the shadow border, which are a typical phenomenon in 3D range data obtained by lidars [23]. This feature is used to classify borders according to the following steps.

**Algorithm 2 (Range Border Detector)**

1. Preparation: *creating a range image from the point cloud data of the object*.
2. Heuristic of distance: *checking each image point and applying a heuristic to find out the 3D distance a certain point typically has to its 2D neighbors that belong to the same surface*:
    a. *For each point* $p_{x,y}$ *in the range image, selecting all neighboring points* $\{n_1, \ldots, n_{s^2}\}$ *that lie in the square of size* $s$ *with* $p_i$ *in the middle; then calculating their 3D distances* $\{d_0, \ldots, d_{s^2}\}$ to $p_{x,y}$.
    b. *Calculating four scores for every image point, describing the probability (the score value) of having a border on the top, left, right, or bottom*.
3. Smoothing: *applying a smoothing operation on the score values to achieve continuous borders and avoid disruptions coming from sensor noise*.
4. Border criteria: *checking if the score value is above a threshold and if it is a maximum regarding* $p_{x-1,y}$ *and* $p_{x+1,y}$. *If so,* $p_{x,y}$ *is marked as an obstacle border, its counterpart from above as a shadow border, and all pixels in between as veil points*.

The border of the object is extracted by range border extractor and displayed in the point cloud as shown in Fig. 6, in which shadow borders are marked as blue points, veil points are marked as red points and obstacle border are marked as green points.

**Fig. 7** Merging edges into 3D point cloud from range image




## *3.3 Edge Data Merging Mechanisms*

### 3.3.1 Merging Range Edges into Point Cloud Data

For processing point cloud and range image data, the point cloud library (PCL) [15] is adopted to make use of its state-of-the art of 3D and 2D processing algorithms. In PCL, the RangeImage class is derived from pcl/PointCloud. It provides functionalities with focus on situations where a 3D scene is captured from a specific view point. This makes it very handy to generate range images from point cloud data, perform border extraction on it and convert range pixel data into point cloud data as shown in Fig. 7.

Step 1: generating range image data from point cloud data;

Step 2: extracting edges of range image by the edge detecting operator of the *RangeImage* class;

Step 3: since the class for range images generating and processing is derived from the *PointCloud* base class, the edges extracted by the detector on the range image can be mapped into the point cloud with coordinate values that range image retains for each pixel.

### 3.3.2 Merging 2D Image Edges into Point Cloud Data

The premise of establishing the correspondence between 2D image and 3D point cloud data is that they share the identical indexing so that each pixel on the image can be mapped to the corresponding location in point cloud only by using its planar coordinate values. 2D image data captured by 3D visual sensor contains location information (XY coordinate values) and color information (RGB values) and the 3D PCD used in our work have 4 fields: X, Y, Z fields and color field and each point is placed one by one in rows. To merge 2D image edges into point cloud data, the main steps are required as Fig. 8 shows:

- Loading the 2D image of the object and performing Canny edge extractor on it after some pre-processing operations, such as converting the image to grayscale and blurring it to denoise.

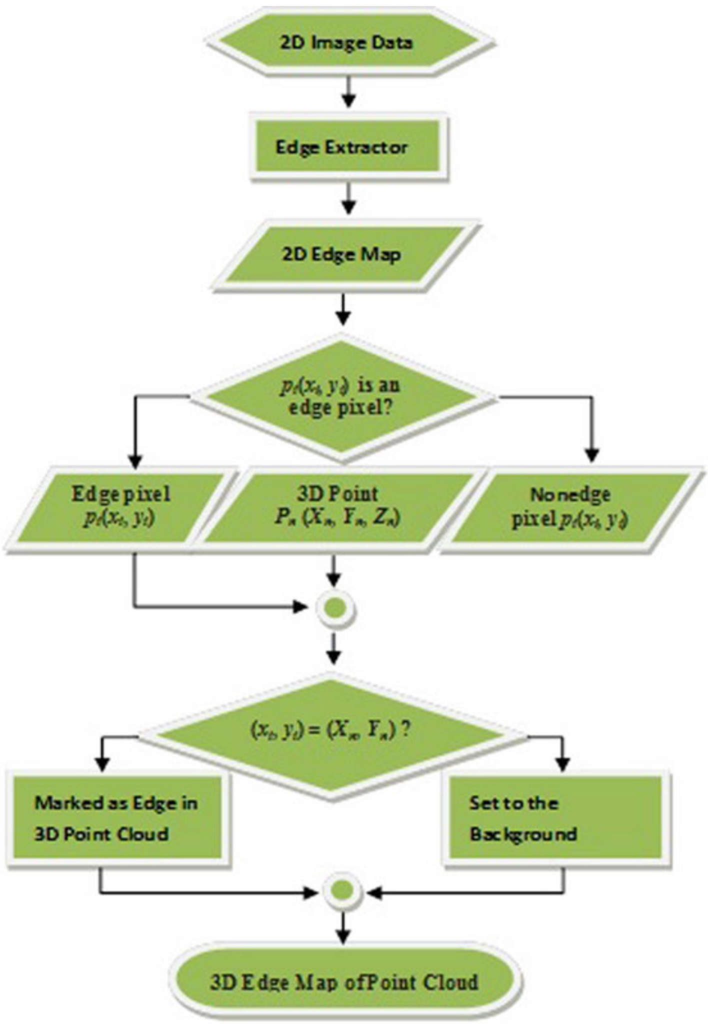



**Fig. 8** Merging 2D image edges to 3D point cloud

- Forming edge correspondence by mapping only the areas of the image that are identified as edges on a black background and resulting in an image with detected edges represented by white pixels in a black background.
- Examining each pixel $p_i(x_i, y_i)$ on the edge map whether it is an edge pixel or not. If an edge pixel is found, its coordinate values will be used to find the matching point that has the identical XY values in PCD.
- Marking the edge pixel by retaining its position information while setting the nonedge pixels to the background, so as to establish a 3D edge map in PCD.

**Fig. 9** 3D edge map merging from 2D and 3D images

# 4 Preliminary Results

In the last section, the Canny edge extractor is performed on the object with a piece of white paper as background in Fig. 2. The results with the low thresholds at 5, 24 and 40 are displayed respectively in Figs. 3, 4 and 5. It can be seen that 2D edge extractor is very sensitive to reflectance and illumination in the image. The irregularity of the background surface are captured and identified as edges in Figs. 3 and 4, as well as the object's shadow. With the rise of the low threshold of the edge extractor, the surface irregularity and the shadow are eliminated from Fig. 5, at the price of losing a few of the actual edges of the object.

The original point cloud is used to generate a range image for border extractor to operate on. All the extracted border points in the range image are mapped back to the point cloud, as shown in Fig. 6. The object's border, outlined by the green points, is identified in the image and distinguished from shadow and veil borders owing to the depth information every point carries. Furthermore, an agreement can be made on the correctness of mapping the range image pixels into point cloud by observing the border points in Fig. 6.

The final result of our 2D-3D edge merging algorithm is shown in Fig. 9. Compared to edge extraction results in both 2D and 3D methods, our proposed algorithm is able to obtain a larger collection of edge pixels and display them in 3D point cloud. Obviously, 2D edge pixels are correctly fused into the point cloud with our 2D-3D pixel mapping mechanism. However, the 3D edges do not match the edge features of the object perfectly as the spout part in Fig. 9 fall back into the background for the loss of actual depth information. The cause to this phenomenon is that the edge detecting accuracies are different in 2D and 3D processing. Therefore when the spout edge part detected in 2D image is mapped into the point cloud, instead of corresponding to the edge points, the background points, which are in the vicinity of the spout edge in XY coordinates, are identified as edges.

# 5 Conclusions and Future Work

## *5.1 Conclusions*

A novel approach to fusing edge data extracted in 2D image and 3D point cloud data is introduced and validated, accomplishing the goals of:

- retaining the 3D information in point clouds provided by 3D sensors;
- being able to extract more edge features compared to either edge extracting approach;
- avoiding the side effect caused by lighting condition on edge extraction in 2D image processing, e. g. shadows;
- fusing 2D image data and 3D point cloud data by a simple pixel corresponding mechanism.

However, some flaws exist in our work as it can be seen from Figs. 6 and 9 that the border feature of the spout on the object is not well restored. Owing to the defect of identifying spout border from the background in the range image, the fused edges at the counterpart lose the Z coordinate values, thus falling into the background.

### 5.2 Future Work

To continue and advance our work in 3D edge detection, besides addressing the above-mentioned issue, research efforts will be made on evaluating and optimizing our proposed approach regarding its accuracy and precision levels; color information will be taken into account to eliminate mismatching between 2D edge pixels and point cloud data due to different accuracy ranges of edge points; adaptive extraction will be developed to apply on real-time region growing cases, e. g. extracting edges in videos and simultaneously merging them into point clouds and displaying the merging results on point clouds.

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# Work Area Monitoring in Dynamic Environments Using Multiple Auto-aligning 3D Sensors

**Ying Wang, Daniel Ewert, Tobias Meisen, Daniel Schilberg and Sabina Jeschke**

**Abstract** Compared to current industry standards future production systems will be more flexible and robust and will adapt to unforeseen states and events. Industrial robots will interact with each other as well as with human coworkers. To be able to act in such a dynamic environment, each acting entity ideally needs complete knowledge of its surroundings, concerning working materials as well as other working entities. Therefore new monitoring methods providing complete coverage for complex and changing working areas are needed. While single 3D sensors already provide detailed information within their field of view, complete coverage of a complete work area can only be achieved by relying on a multitude of these sensors.

However, to provide useful information all data of each sensor must be aligned to each other and fused into an overall world picture. To be able to align the data correctly, the position and orientation of each sensor must be known with sufficient exactness. In a quickly changing dynamic environment, the positions of sensors are not fixed, but must be adjusted to maintain optimal coverage. Therefore, the sensors need to autonomously align themselves in real-time. This can be achieved by adding defined markers with given geometrical patterns to the environment which can be used for calibration and localization of each sensor. As soon as two sensors detect the same marker, their relative position to each other can be calculated. Additional anchor markers at fixed positions serve as global reference points for the base coordinate system.

In this paper we present a prototype for a self-aligning monitoring system based on ROS and Microsoft Kinects. This system is capable of autonomously real-time calibrating itself relatively and in respect to a global coordinate system as well as to detect and track defined objects within the working area.

**Keywords** Measurement · Intelligent Instruments · Kinect · Self-Alignment · Real-Time Monitoring

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# 1 Introduction

The ability to autonomously acquire new knowledge through interaction with the environment has been in the focus of significant research in the field of dynamic work area. Challenging research topics arise in pose estimation, sensor alignment and object recognition. In order to accurately manipulating the objects in a dynamic work area, a reliable and precise vision system is required in a robotic system to detect and track workpieces and to monitor the operation of the robots to accomplish manufacturing tasks such as assembly planning [1]. Such a vision system not only has to be aware of the presence and location information in the working site, but also needs to have the information of its own real-time position and orientation as sensors.

Rather than being fixed, the vision system has to be able to move accordingly to provide a complete coverage in a dynamic scenario. To meet the above-mentioned requirements, we present a prototype for a self-aligning monitoring system based on ROS and Microsoft Kinects. This system is capable of autonomously calibrating itself relatively and in respect to a global coordinate system as well as to detect and track defined objects within the working area.

The proposed 3D monitoring system, comprised of multiple Microsoft Kinects, is capable of self-alignment through calibrating Kinects both individually and as a stereo camera with reference to markers to obtain the relative location information between each other, as well as their pose in the global coordinate system. Two Kinects placed with a certain angle and distance with regards to each other can enable a full view of the working site if the image data from them are correctly aligned and fused. Experimental studies are carried out in the test platform which uses two Kinects and two ABB robots to represent the general case of multiple sensors and robots as Fig. 1 shows. While single 3D sensors already provide detailed information within their field of view, complete coverage of a complete work area can only be achieved by relying on a multitude of these sensors. However, to provide useful information all data of each sensor must be aligned to each other, integrated and fused into an overall world picture. Therefore, it is of vital importance for sensors to be aware of not only its real-time pose in the real world but also their relative position and orientation to each other, so as to reconstruct 3D view of the working site.

To be able to align the data correctly, the position and orientation of each sensor must be known with sufficient exactness. To address this problem, a fixed marker is introduced into the system as an anchor. With the marker in sight, the Kinect matches the marker's location in the 2D image with that in the real world coordinate system to get the transformation from real world coordinate system to camera system. As Kinects are not fixed in the dynamic work area, there are circumstances that Kinects do not detect the same geometrical marker for direct estimation of relative pose between them or one or both Kinects do not detect the anchor marker for self-positioning in the real world. Different relationships among Kinects and markers are considered and classified and corresponding solutions are presented in the following section.

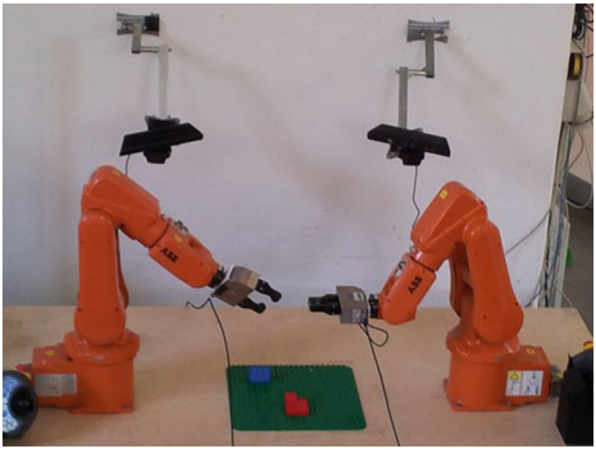

**Fig. 1** The test platform of the monitoring system

Besides being able to be aware of its sensing element's pose relative to each other and with regards to the world coordinate, a vision based monitoring system is required to interpret a scene, which is defined as an instance of the real world consisting of one or more 3D objects, to a determination of which 3D objects are where in the scene. Therefore two main problems are involved: the first is object recognition, in which a label must be assigned to an object in the scene, indicating the category to which it belongs. The second involves the position and orientation estimation of the recognized object with respect to some global coordinate system attached to the scene. We adopt the VFH method to deal with the object recognition and 6DOF pose estimation will be discussed. It uses a two-dimensional Cartesian Histogram Grid as a world model, which is updated continuously and in real-time with range data sampled by Kinects thus enabling real-time performance of the vision system.

The remainder of the paper is organized as follows: Sect. 2 presents a brief review of the recent literature about object recognition approaches in industrial vision that are relevant to our proposed vision system. The architecture and workflow of industrial vision monitoring systems are discussed in Sect. 3. Software and hardware tools, sensor alignment and object recognition approaches that are used in assisting the development of the proposed vision systems are presented in Sect. 4. Section 5 summarizes the contribution of this work and plans about future work.

## 2 Related Work

Much research attention has been drawn to workpiece position and orientation estimation in the industrial robot area, which is the primary requirement of industrial robot monitoring. A good variety of approaches have been proposed to solve object pose detection and their categorization. Literatures classify between model- and view-based approaches [2, 3], feature- and appearance- based approaches or introduces several classes [4]. Among all other methods, the model of the object and the image data are represented by local geometric features. Geometric feature matching is used to interpret images through matching the model of object to data feature and estimating 3D pose of the model. The shape, texture or the appearance of the object is always the center of attention. Because object matching between the model and scene data depends on this information to make reliable interpretation which allows for reasonable inferences about the scene information under explicit 2D image data. We apply the model-based pose estimation approach in our research, which is done by matching geometric representations of a model of the object to those of the image data.

Besides object pose estimation, sensor self-positioning is another topic that researchers have been interested in and many efforts have been made in using and comparing marker and markerless pose estimation. Quite a few vision-based applications: camera calibration, augmented reality and so on has benefited from the use of artificial 2D and 3D markers. These markers are designed to be easily detected and require very simple image processing operations. As to geometry, some applications are specially designed to avoid the trouble of estimating object pose. Typically, markerless object detection and pose estimation start with features extraction [5–8]. Other methods based on affine invariant regions determined around feature points were proposed [5, 9–12] in order to obtain invariance to out-of-plane rotations and translations. However, these algorithms are too time-consuming to meet the requirement of real-time computing speed. A registration method was proposed by State using stereo images and a magnetic tracker [13]. Vision techniques, multiple fiducial markers and square markers were used respectively for identifying 2D matrix, markers robust tracking and fast tracking [14–16]. In our research, markers with distinct and simple geometrical patterns are used to attach on objects for recognizing and tracking, as they are easy to detect and recognize, thus achieving both robust and fast tracking.

We are proposing a real-time self-aligning multi-sensor vision monitoring system for dynamic work area. Model-based pose estimation approach and VFH method are applied for object recognition and 6 DOF estimation; anchor markers are used for sensor self-alignment and simple geometrical markers are attached on objects to distinguish and track them, which enables the monitoring system to be aware of the real-time position and pose status of sensing elements, robots and objects in it.

## 3 System Overview

### *3.1 System Architecture*

The monitoring mechanism of the proposed test system is shown in Fig. 2. The markers form Geometric Inference, which is used on a robot software development platform ROS to implement self-alignment of multi-sensors. ROS is also used to

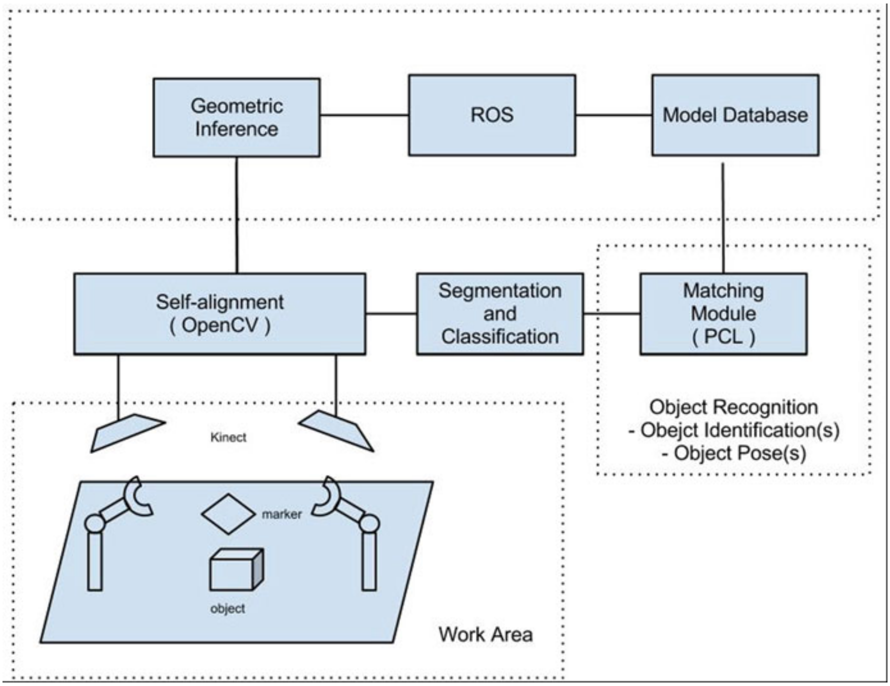


**Fig. 2** System architecture

create 3D object point cloud models which compose Model Database for object recognition and pose estimation by Matching Module after the overall scene image is processed by Segmentation and Classification module.

## 3.2 Workflow

Figure 3 is the workflow of monitoring object's movement in the work area.

*Kinect Launching* ROS camera driver launches Kinect and outputs 2D/3D image data.

*Calibration* Calibrate a single Kinect with an anchor maker in work area. From the calibration the location of the points on the marker and its counterparts in the image, the transformation between marker and camera coordinate can be obtained. Since the location in the world coordinate is already known, thus, Kinect implement self-positioning.

*Alignment* Align every Kinect pair as a stereo camera. As two Kinect detects the same marker, they register their captured images at the corresponding points and

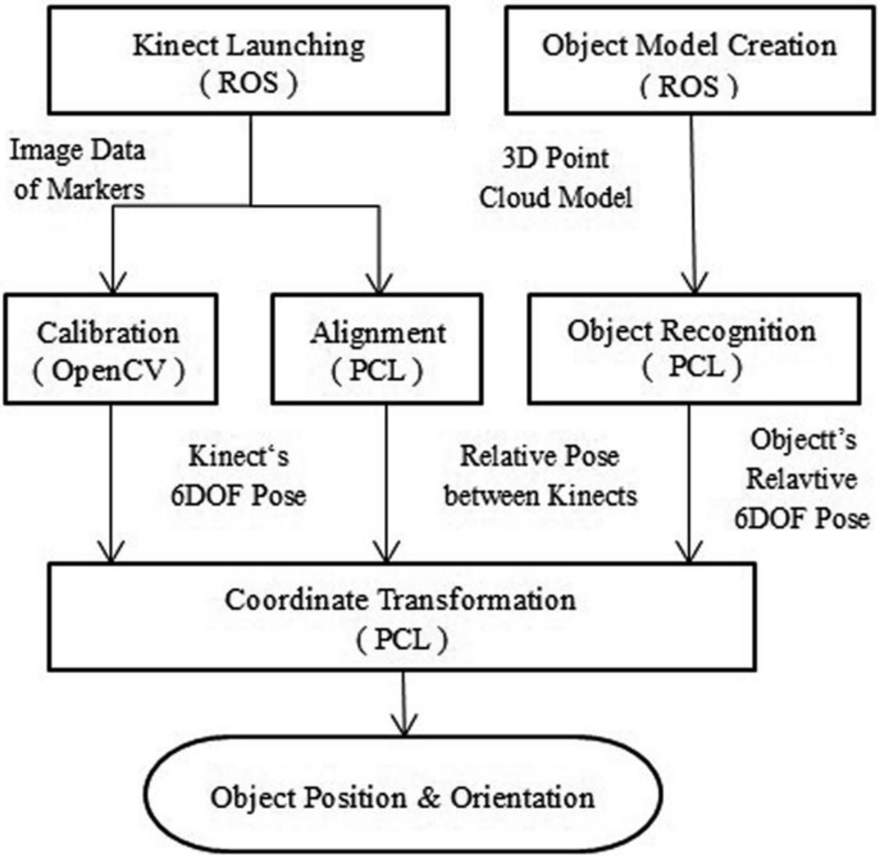


**Fig. 3** Workflow of the vision monitoring system

compute the relative position and orientation between the Kinects, thus align the image from the two Kinects to visualize the work area.

*Object Model Creation* Create 3D point cloud model of object for later recognition and alignment.

*Object Recognition* Recognize and position the object from the scene. Object relative position and orientation will be obtained through aligning object model to the point cloud of current scene.

*Coordinate Transformation* Transform object pose which is relative to scene in camera coordinate system to global coordinate system.

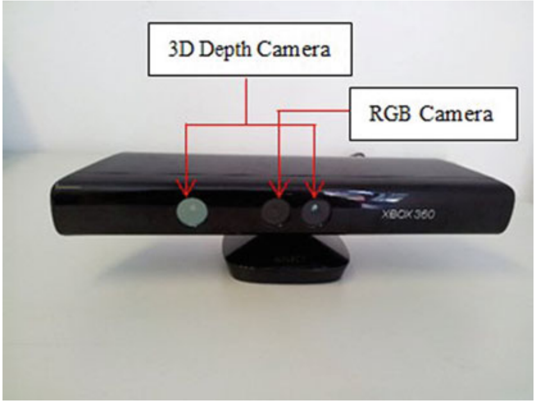


**Fig. 4** Microsoft Kinect

# 4 Tools and Methods

## *4.1 Tools*

### 4.1.1 Kinect

The robot has to rely on its sensory feedback to build a model of its surroundings. The 3D sensor used in our research is Microsoft Kinect. It is able to capture the surrounding world in 3D by combining the information from depth sensors and a standard RGB camera as shown in Fig. 4. The result of this combination is an RGB-D image with $640 \times 480$ resolution, where each pixel is assigned color information and depth information. In ideal conditions the resolution of the depth information can be as high as 3 mm, using 11 bit resolution. Kinect works with the frequency 30 Hz for both RGB and depth cameras. On the left side of the Kinect is a laser infrared light source that generates electromagnetic waves with the frequency of 830 nm. Information is encoded in light patterns that are deformed as the light reflects from objects in front of the Kinect. Based on these deformations captured by the sensor on the right side of RGB camera a depth map is created. According to PrimeSense this is not the time-of-flight method used in other 3D cameras [17].

### 4.1.2 ROS

Robot Operating System (ROS) [18] is a software framework for robot software development, providing standard operating system services such as hardware abstraction, low-level device control implementation of commonly-used functionality, message- passing between processes, and package management. It is based on a graph architecture where processing takes place in nodes that may receive, post and multiplex sensor, control, state, planning, actuator and other messages.

ROS is composed of two main parts: the operating system ros as described above and *ros-pkg*, a suite of user contributed packages that implement functionality such as simultaneous localization and mapping, planning, perception, simulation etc. The Kinect node package provides a driver for using the Kinect RGB-D sensor with ROS, which launches an OpenNI device and load all nodelets to convert raw depth/RGB/IR streams to depth image, disparity image and registered point clouds. So it outputs point clouds, RGB image messages and its associated camera information for calibration, object recognition and alignment.

#### 4.1.3 PCL

The Point Cloud Library (PCL) [19] is a large scale, open project for 2D/3D image and point cloud processing. The PCL framework contains numerous state-of-the art algorithms including filtering, feature estimation, surface reconstruction, registration, model fitting and segmentation. These algorithms can be used, for example, to filter outliers from noisy data, stitch 3D point clouds together, segment relevant parts of a scene, extract keypoints and compute descriptors to recognize objects in the world based on their geometric appearance, and create surfaces from point clouds and visualize.

#### 4.1.4 OpenCV

OpenCV (Open Source Computer Vision Library) [20] is an open source computer vision and machine learning software library. OpenCV was built to provide a common infrastructure for computer vision applications and to accelerate the use of machine perception in the commercial products. The library has a comprehensive set of both classic and state-of-the-art computer vision and machine learning algorithms.

### *4.2 Methods and Mechanism*

#### 4.2.1 Sensor Alignment

In the proposed vision monitoring system, multiple sensors are used and must be aligned to each other and fused into an overall world picture. In order to align the sensing data accurately, the position and orientation of each sensor are the priori to align the sensing data accurately. The introduction of anchor markers and geometrical markers ensure the reconstruction of the whole scene of the work area. Instead of being fixed in the work area, Kinects move up and down, left and right on their bases to obtain visual information of work scene from different viewpoint. Therefore, the spatial relationships of anchor markers, geometrical markers and Kinects vary from time to time. The relative pose of Kinects can be generally summarized and classified into four cases, as shown in Fig. 5.

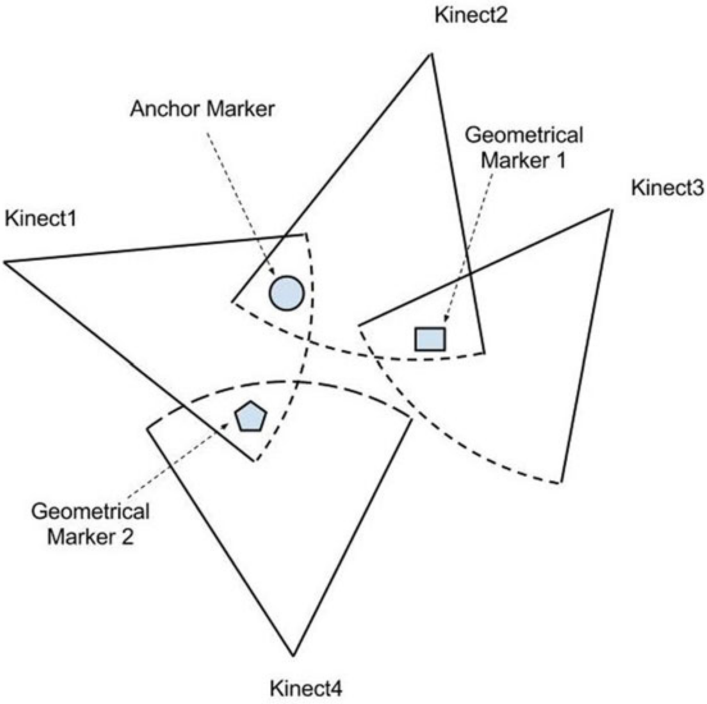


**Fig. 5** Three possible relative cases of multiple sensors

1. Kinect 1 and Kinect 2 have at least one anchor marker in their intersected vision area;
2. Kinect 2 and Kinect 3 have at least one distinguishing marker and no anchor marker in their intersected vision area;
3. Two Kinects have no common marker in their intersected vision area:
   a. Kinect 1 can position itself by anchor marker; Kinect 3 has no anchor marker in its sight but a geometrical marker;
   b. Both Kinect 3 and 4 detect no anchor marker but geometrical markers.

For case 1, Kinect 1 and 2 can use the anchor marker in sight for their own 3D pose estimation through for relating camera measurements with measurements in the real, three-dimensional world. In this model, a marker scene view is formed by projecting 3D points of the marker into the image plane using a perspective transformation as Fig. 6 shows:

Projective transform maps the points $Q_m$ in the global world coordinate system ($X_m$,$Y_m$,$Z_m$) to the points on the image plane with coordinates ($x_i$,$y_i$) and to the points on camera plane with coordinates ($X_c$,$Y_c$,$Z_c$). The projection from global

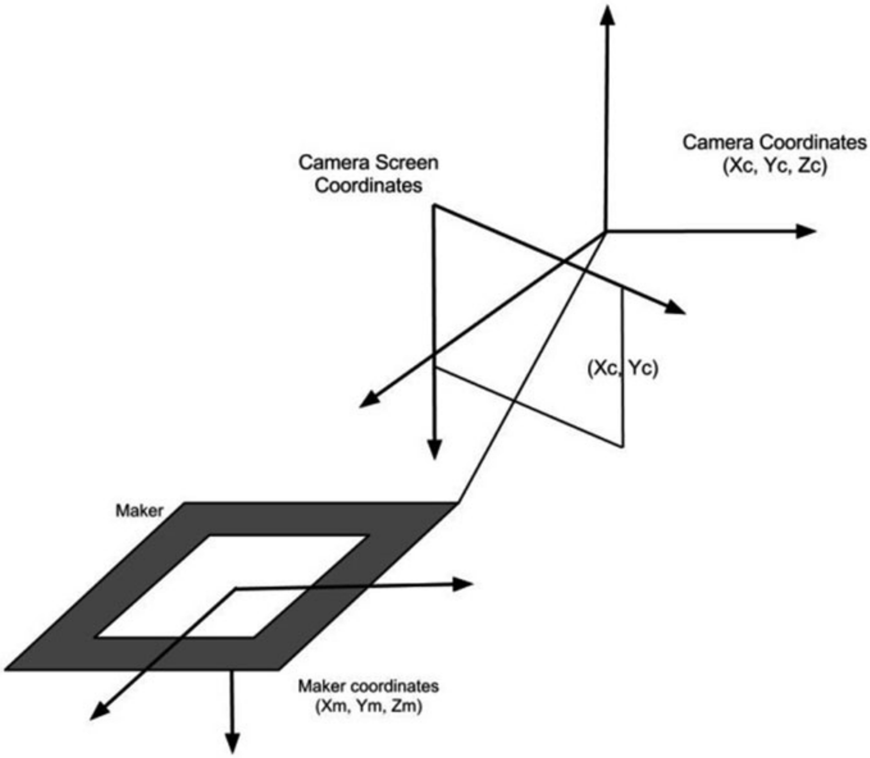


**Fig. 6** The relationship between marker and camera coordinate

world coordinate system to camera image coordinate system can be summarized as Eq. 1:

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \\ 1 \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_1 \\ r_{21} & r_{22} & r_{23} & t_2 \\ r_{31} & r_{32} & r_{33} & t_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_m \\ Y_m \\ Z_m \\ 1 \end{bmatrix} \tag{1}$$

For case 2, Kinect 2 and 3 capture the same non-anchor marker. For any given 3D point P in object coordinates, we can put P in the camera coordinates $P_l = R_l P + T_l$ and $P_r = R_r P + T_r$ for the left and right cameras, respectively. It is also evident from the two views of $P$ (from the two cameras) are related by $P_l = R^T(P_r - T)$ where R and T are, respectively, the rotation matrix and translation vector between the cameras. Taking these three equations and solving for the rotation and translation separately yields the following simple relations [20]:

$$R = R_r(R_l)^T \tag{2}$$

$$T = T_r - RT_l \quad (3)$$

Then the relative rotation and translate from Kinect 1 to 2 can be obtained, and in the chain of Kinects that detect the same marker with Kinect 2 directly or indirectly, there must be one that have an anchor marker in vision range. Therefore, the second case can be solved as case 1 does only with the corresponding transformations.

For case 3, Kinect 1 and 3 do not have the same marker in their vision ranges. We apply a similar strategy here by searching for anchor marker in the chain composed of overlapped Kinects to estimate 6 DOF pose of at least one Kinect and then to make pose estimation of others through coordinate transformation.

#### 4.2.2 Object Recognition and 6 DOF Pose Estimation

Object recognition is the process of automatic identification and localization of objects from the sensed images of scenes in the real world. For object recognition in this system, scene point clouds with object's presence are downsampled by corresponding sampling algorithm from PCL for analysis and computation. To obtain the surface normals of the specified input point clouds, Kd-Tree [18] is used to search for neighboring point and the radius that defines each point's neighborhood. The computation of VFH [19] (Viewpoint Feature Histogram) descriptors is implemented from the input point cloud and its surface normals. The resulted features are invariant to image scaling, translation, rotation and partially invariant to illumination changes and affine or 3D projection. With the normals and local feature descriptors, the object point cloud model is aligned into the current scene cloud to get final transformation and a fitness score to evaluate the aligning results.

Object recognition is achieved by matching features derived from the scene with stored object model representations. One of the most common ways to create the object model for recognition is to extract the target as a cluster from the point cloud. However, in this way only partial model is created out of the object, which provides very limited information for object identification.

**Model Creation** In this research, the approach adopted to create a 3D point cloud model from an object is to use an object recording API of the package RoboEarth from ROS along with a Kinect camera and a marker pattern. The target object is placed in the middle of the marker template and either the camera or marker pattern and object are moved to record a complete pose. It always is a better idea to move the object, because otherwise the illumination might not be constant and therefore get color effects.

Figure 7 shows the overlapping of point clouds of the object captured at seven different viewpoints and all the point clouds are created at 34 different viewpoints and are finally processed and merged into one 3D point cloud model as Fig. 8 shows:

**Normals Estimation** Given a geometric surface, it's usually trivial to infer the direction of the normal at a certain point on the surface as the vector perpendicular

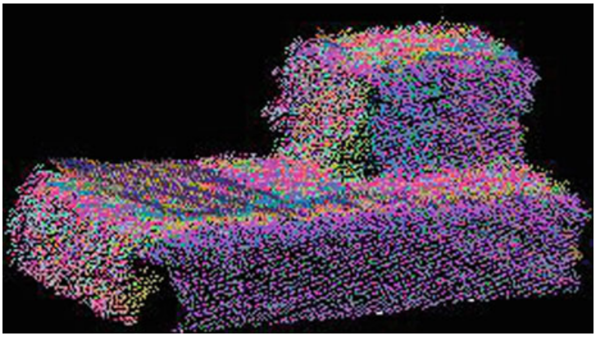

**Fig. 7** Overlapping of seven point clouds at different viewpoints

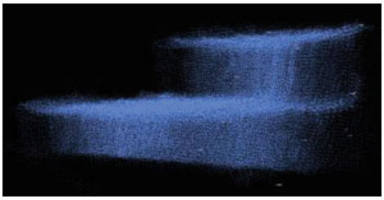

**Fig. 8** Merging of 34 point clouds at 34 different viewpoints

to the surface in that point. The problem of determining the normal to a point on the surface is approximated by the problem of estimating the normal of a plane tangent to the surface, which in turn becomes a least-square plane fitting estimation problem. The solution for estimating the surface normal is therefore reduced to an analysis of the eigenvectors and eigenvalues of a covariance matrix created from the nearest neighbors of the query point. More specifically, for each point $\mathrm{p}_i$, we assemble the covariance matrix C as follows:

$$C = \frac{1}{k}\sum_{i=1}^{k}(p_i - \bar{p}) \cdot (p_i - \bar{p})^T \tag{4}$$

$$C \cdot \vec{v_j} = \lambda_j \cdot \vec{v_j}, j \in \{0, 1, 2\} \tag{5}$$

Where $k$ is the number of point neighbors considered in the neighborhood of $p_i$, $p$ represents the 3D centroid of the nearest neighbors, $\lambda_j$ is the j-th eigenvalue of the covariance matrix, and $v_j$ the j-th eigenvector [21].

**Feature Description** Features define individual components of an image and can be categorized into two major groups: global features and local features. Global features are defined as properties of an image based on the whole image. Local features are defined as properties of an image based on a component of the image and these will be used for object recognition. Therefore, we need a way to describe the features of an image.

VFH descriptor is a novel representation for point cluster recognition and its 6 DOF pose estimation. VFH has its roots in FPFH (Fast Point Feature Histograms) descriptor and add in viewpoint variance while retaining invariance to scale. The main idea of object recognition through VFH descriptors is to formulate the recognition problem as a nearest neighborhood estimation problem. Let $p_c$ and $n_c$ be the centroids of all surface points and their normals of a given object partial view in the camera coordinate system (with $||n_c|| = 1$). Then $(u_i, v_i, w_i)$ defines a Darboux coordinate frame for each point $p_i$:

$$u_i = n_c \tag{6}$$

$$v_i = \frac{p_i - p_c}{||p_i - p_c||} \times u_i \tag{7}$$

$$w_i = u_i \times v_i \tag{8}$$

The normal angular deviations $\cos(\alpha_i)$, $\cos(\beta_i)$ and $\cos(\varnothing_i)$ for each point $p_i$ and its normal $n_i$ given by:

$$\cos(\alpha_i) = v_i \cdot n_i \tag{9}$$

$$\cos(\beta_i) = n_i \cdot \frac{p_c}{||p_c||} \tag{10}$$

$$\cos(\varnothing_i) = u_i \cdot \frac{p_i - p_c}{||p_i - p_c||} \tag{11}$$

$$\theta_i = \text{atan2}(w_i \cdot n_i, u_i \cdot n_i) \tag{12}$$

Note that $\cos(\alpha_i)$, $\cos(\varnothing_i)$ and $\theta_i$ are invariant to viewpoint changes, given that the set of visible points does not change. For $\cos(\alpha_i)$, $\cos(\varnothing_i)$ and $\theta_i$ histograms with 45 bins each are computed and a histogram of 128 bins for $\cos(\beta_i)$, thus the VFH descriptor has 263 dimensions [22].

**Pose Estimation** As the point cloud data of object model is stored and the corresponding Kd-tree representation is built up, objects are extracted from the given scene as clusters and for each of them, an individual cluster; for each cluster, their VFH descriptor from the current camera position is computed for searching for candidates in the trained Kd-tree. After find the best candidate for recognition, the position and orientation of the object that the model represents can be determined by registering the model to the scene point cloud.

## 5 Conclusions

In this paper, we have introduced a new approach for work area monitoring in dynamic environment using multiple 3D self-aligning Kinect. The anchor marker is used to calibrate Kinect to correct for the main deviations from the pinhole model that Kinect uses, to obtain the transformations from global coordinate system to camera coordinate system and relative position and orientation between the Kinects. In this way, Kinects are able to have an awareness of their own positions and 6DOF poses as well as the object's location in the working scenario at any moment, enabling robots to accommodate changes in the workpiece position/orientation and to perform complex operations like automated assembling and sorting. Simple geometrical markers are used to distinguish objects, which achieves robust and fast tracking of objects in dynamic work sites. In conclusion, addressing the requirements of real-time monitoring of dynamic industrial production area, the proposed vision monitoring system is able to provide overall vision of the work area and estimate 6 DOF pose of multiple objects with defined geometrical markers and anchor markers.

To evaluate and optimize the performance of our proposed approaches in this vision system, we will involve the following aspects as future research topics. Firstly, adopt color information for object recognition and extraction; secondly, implement boundary analysis using the combination of photogrammetric processing algorithm and point cloud spatial information; thirdly, compare the results of using different model to align to scene image: 3D CAD model, model generated based on both digital image and point cloud obtained by depth camera, scanned object 3D point cloud model and object model extracted from the scene image.

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# Creating a Reasonable Basis for Evaluation: A Cybernetic Approach for the Development of a Methodology to Identify the Value Proposition of Enterprise IT

**Philipp Wolters, Katharina Tarnacki, Eckart Hauck and Sabina Jeschke**

**Abstract** The concept of value creation is essential for the analysis of human decision-making. Basically, whatever we do is based on subconscious decision processes, which are based on available information. If there are inadequate or insufficient information it is hard to decide what to do and a mandatory decision is mostly more a game of luck. Based on a cybernetic structural model of value creation a methodology is proposed to overcome the problem of insufficient information in a decision process. The approach is motivated by the problem of identifying the value proposition of Enterprise IT in order to make an investment decision.

**Keywords** Decision-Making · Value Proposition · IT Management · Cybernetics

## 1 Introduction

Information and communication technologies (ICT) are omnipresent in all kind of enterprises. ICT are key factors for supporting business processes regarding their productivity. Permanent innovations within the ICT sector and its consequences on the productivity of organizations require a well-managed IT department. Therefore nearly every enterprise has one. On the one hand the IT department creates added value for the enterprise, on the other it ties up large amount of capital and staff and thereby generates significant costs. To encourage a sustainable development, CEOs (Chief Executive Officers) need to question themselves: Does the IT department serve efficiently and productively towards the enterprise's success? (cp. [1, 2])

To ensure that productivity of business processes, defined as the quotient between output and input (cp. [3, p. 355]), is not falling behind the standards of the market it is necessary to invest in the right area of the enterprise's IT. That way an enterprise prevails and can invest free resources in further product innovations.

ICT support of standard processes is especially important for enterprises, which primary selling products are not mainly a service rather than a physical product,

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i. e. true for machinery and plant engineering enterprises (cp. [4]). Rapid innovation cycles of ICT make permanent investments unavoidable to increase the overall productivity of such enterprises (cp. [5]). These lasting investments and general operating expenses have introduced the IT reputation as a cost center losing the focus of generating significant benefits for the enterprise (cp. [6, p. 8]). The challenge is to point out main benefits and to quantify them for the higher management in an acceptable manner (cp. [7]). Thus the question arises of how the cost-benefit ratio for IT-services can be extracted from overall generated value of the company? In other words: What is the value proposition of the IT?

Based on such information and reliable propositions enterprises have the chance to decide, where to invest within the IT to increase productivity or the other way around to decrease costs for the same productivity. To quantify the benefit effects IT has on business is a challenge, which is not solved until today. One reason is: processes and enterprise structures are cross-linked to a great extent, so that a correlation between IT and costs or benefits cannot be clearly identified. For a CEO this means, that he can hardly answer the question due to lack of reliable information: How valuable is my IT for the standard processes? This fact results in the situation that decisions concerning IT investments are more a game of luck then a comprehensible conclusion (cp. [7, 8, 413 f., 9]). The objective of this research is to describe value in model-based structure in order to operationalize it for the measurement of the value added by the IT for an enterprise.

In this paper the relationship between IT and enterprises is described, to clarify the challenge of IT-value and productivity. Afterwards a cybernetically based theoretical foundation of a value concept is introduced and its formal structural model. On that basis fundamental requirements for an evaluation are formulated. Moreover, a three-step approach in order to challenge the problem of quantifying the value proposition of IT is suggested. The paper concludes with a summary and an outlook on future research and applications of methodology.

## 2 IT and Enterprises

IT and enterprises are acting in a co-evolutionary relationship (cp. [10, p. 4]). On the one hand ICT supports enterprises and their standard processes, because it influences economic effects (productivity gains) as a part of the enterprise development. On the other hand the enterprise development is influenced by its success and its further progress. For IT that means: If the enterprise is changing, the IT will need to adapt to these new conditions (cp. [12, 181 f.]). This kind of evolutionary dependency can be called, in the words of Luhmann: structural coupling (cp. [13, p. 1432]). Because of the high ability of IT to change, it turns out to be a fundamental competitive driver nowadays. Structural coupling of the two social-economic systems IT and enterprise is interlinked by the "milieu business processes" (cp. Fig. 1).

The overall strategic goal of business processes is being as productive as possible. This is because in essence they are the business activities, which generate added value.

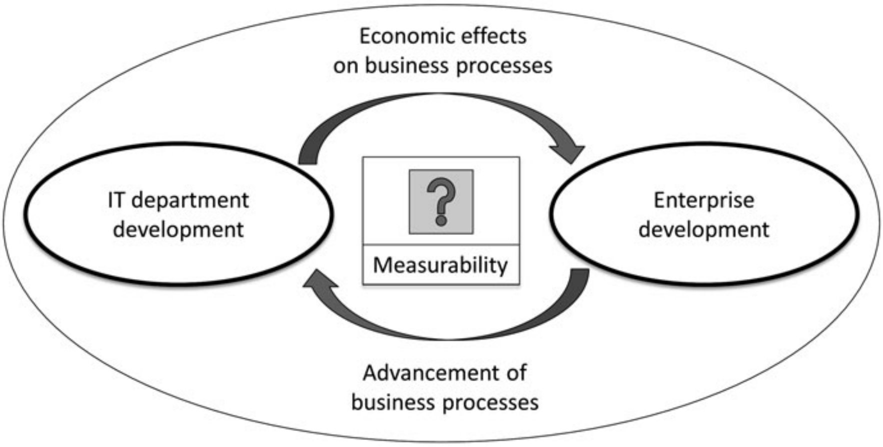


**Fig. 1** Structural coupling of IT and enterprise. (Source: own illustration based on Strina [11, p. 50])

Therefore, business processes are the primary levers of value proposition of IT (cp. [14, p. 10]). Consequently changes within the enterprise result in direct or indirect investments or divestments in IT, which are followed by economic effects on business processes. Those effects can be of a positive or negative nature, which is not clear because the question about the evaluation will be answered at a later stage. Evaluation processes strongly depend on available information such as accompanying measuring processes. Measurement results serve to evaluate a product, a process or an object. So first of all, it must be clear how the economic effects can be measured (cp. [14, 8 f.]).

Those measurements should be aligned in such a way that they capture the effects regarding the overall strategic goal. This leads to the requirement to formulate a target system, which is able to capture productivity effects. This target system should best only measure IT related effects, which is until now very difficult and mostly not possible due to the described structural coupling.

Cybernetics focus dynamic systems and specifically their behavior patterns and the interaction between each other by describing them based on Systems theory. By its interdisciplinary approach it can be used to model technical as well as psychological or organizational systems (cp. [11, p. 17]). Thus it serves as a reasonable basis to model IT and enterprise development. By following this approach, which is based on cybernetical structural model of general value creation an abstract target system can be defined. This target system allows a quantitative survey of productivity ratios concerning IT effects in business processes and at the same time serves as the normative basis for an individual enterprise evaluation.

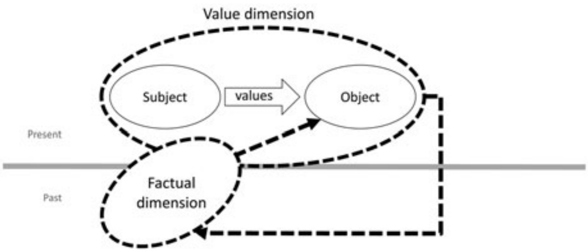


**Fig. 2** Accumulation of value creation due to relationship of factual dimension and value dimension

## 3 Accumulation of Value as a Multidimensional Model

Historically seen the value discussion arises out of philosophy. In the philosophical sense values are part of moral principles for society, persons and groups. Values are guidelines that enable persons to evaluate consequences of their decisions in a positive or a negative way for the system and environment. Evaluation strongly depends on the evaluator with his individual experiences. The evaluator always compares the object to evaluate with his individual evaluation experiences of similar evaluations. Therefore, evaluation is inherently subjective (cp. [15, p. 235, 16, p. 394, 17, 13 f.]).

In the light of the above, value can be described as a subject-object-object-relationship. Value is the result of a benefit assessment of one object by a subject. The subject values the object by comparing the object with individual evaluation experiences. The subject thereby decides if and to what extent the object is valuable or not.

Evaluation in that sense creates a relationship between a value-giving subject, that evaluates, and a value-receiving object, that is being evaluated. This relationship manifests itself in the appraisal of level of satisfaction of one's needs, which can be derived from current personal objectives. Two dimensions can be differentiated (cp. Fig. 2):

**Factual Dimension** Factual dimension compromises factual information about value-received objects. This dimension builds up on past evaluation experiences and works as a basis of comparison in the current evaluation. Relevant information within the dimension is chosen by the characteristics of the value-receiving object.

**Value Dimension** Value dimension is the normative basis for the current evaluation and provides present objectives of the value-giving subject. The former determine the selection and weight of relevant information of the factual dimension, which leads to a so-called scale for the current evaluation (cp. [11, 54 f.]).

Having those two dimensions defined it becomes obvious, that the reason for the subjective point of view of an evaluation can be found within the value dimension. This is because of the selection and weight of relevant information by the value-given subject, which can be seen as individual sub-decisions or in other words sub-evaluations.

So looking at the abstract goal to determine the value proposition of one system of structural coupled systems following principles for evaluating objects can be formulated:

There is no objectively correct evaluation method; it is just more or less adequate for present objectives.

There is no objectively correct evaluation. All evaluations are normative, because they are based on a scale determined by selection and weight of factual information (cp. [11, 54 f.]).

So far the previous argumentation has defined the problem more closely as a problem of subjectivity that needs to be overcome. One way to resolve that problem is to differentiate the introduced dimensions into a structural model. By doing so it is possible to build up evaluation methods that take the value-giving subject and its objectives adequately and transparent into consideration. Therefore a reasonable basis for evaluation can be created.

## 4 Formation of Value as a Structural Model and Application to the Area of Concern

Strina [11] describes a structural model for the formation of value as follows:

A value-giving subject S evaluates a value-receiving object O by comparing it against the background of the objective Z in the situation U by means of the factual model M with its indicators K measured by method V with a reasonable scale Ms. This leads to the evaluation result $E_O$, in short:. $E_O$ = f (S, O, Z, U, M, K, V, Ms). (cp. [11, p. 56])

In the following the area of concern, which is quantifying the value proposition of IT of an enterprise, is applied to the structural model (Fig. 3):

An enterprise (S) wants to evaluate its IT (O). Purpose of evaluation is a statement about the current (U) value proposition of IT by means of productivity in business processes (Z). To do that a factual model in terms of a selection of the IT support for a specific business process (M) with its relevant productivity indicators (K), which are gathered by a specific measurement (V), is used to compare against a scale (Ms). The comparison leads to the value proposition of IT (EO).

The biggest problem within this approach is the lack of a reasonable scale (Ms) for comparison. So an enterprise could use key figures of past measurements. But those figures are related to a different situation. On the one hand, the market situation could be significantly different when the key figures were gathered. On the other hand, the enterprise itself was probably in different state. A comparison could show improvements or deteriorations in specific business processes, but the reason for them is hard to trace back to the IT.

A solution for the missing scale is the use of key figures for comparison, which represent the average of figures, gathered at the same time and within sufficiently similar enterprises based on the same characteristics of the structural model for

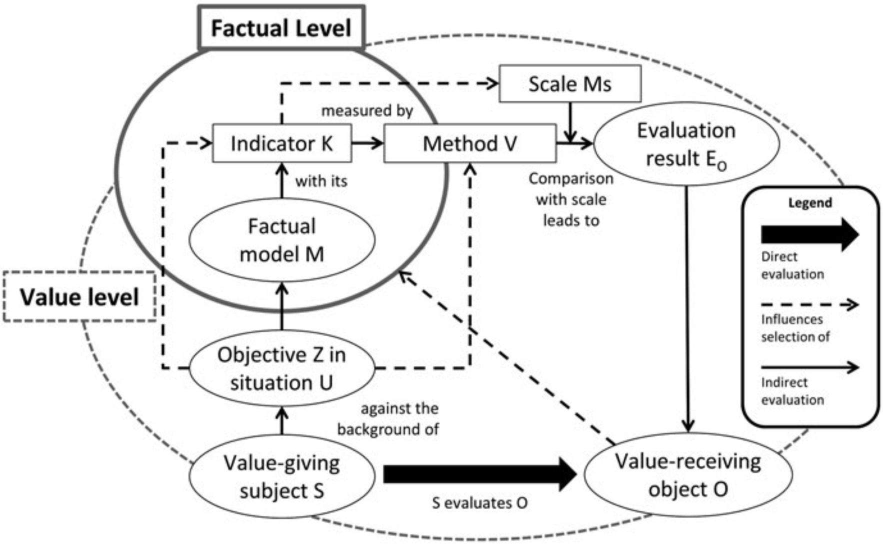


**Fig. 3** Structural model consisting of the correlation of eight entities. (Source: own illustration based on Strina [11, p. 56])

value formation. This can be achieved by creating an industry sector specific benchmark. For the creation of such a benchmark the described structural model of value formation needs further differentiation:

Categorization of enterprise types: An enterprise S has different properties $e_1, \ldots, e_t$, which determine typical IT characteristics. Depending on the properties a typology is defined, which makes a reasonable comparison of the IT between enterprises of the same type possible.

A factual model M determines IT characteristics $m_1, \ldots, m_n$ in all business processes. This model enables the enterprises to select the currently implemented IT focusing on functionality rather than selecting the real product, which is in use. Those characteristics must describe the implemented IT sufficiently precisely to differentiate business process support.

Indicators $Kz_1, \ldots, Kz_p$ sufficiently capture the productivity of supporting a business process in a key figure. Thus by adding up all key figures gathered by an industry sector specific benchmark scales $Ms_1, \ldots, Ms_j$ are created for the different enterprise types. The scale within an enterprise type can then be used to compare the individual gathered key figure with the enterprise type average.

Those three differentiations of the structural model of value formation manifest fundamental preconditions if using it for a methodology to evaluate value proposition of IT. The factual model with its key figures is the basis for comparison. This is achieved by creating enterprise types, which are comparable due to sufficiently similar properties. Thus an industry sector benchmark allows a quantification of the individual value proposition of IT (cp. [8, p. 492]). On this account following preconditions (Pre) must be fulfilled:

**Pre 1** An enterprise must be categorized as a specific enterprise type through different properties $e_1, \ldots, e_t$, which determine typical IT characteristics.

**Pre 2** An IT product, supporting a business process, must be selected in a factual model M by means of its functional characteristics $m_1, \ldots, m_n$ regarding business process support, while its productivity must be captured by indicators $Kz_1, \ldots, Kz_p$.

**Pre 3** Pre 2 must be used to create enterprise type (pre 1) specific scales $Ms_1, \ldots, Ms_j$ based on the factual model M to build a basis for comparison for the individual IT support in business processes.

## 5 Procedure Model to Evaluate Value Proposition of IT

If pre 1 (enterprise type) and pre 2 (factual model) are fulfilled pre 3 (scales for comparison) is enabled through an industry specific benchmark. Thus to evaluate the value proposition of IT of an enterprise following three-step procedure model is suggested. It is based on the requirements, which means to categorize the enterprise first, second to identify the individual IT characteristics and their performance, and third to compare it to a measurement to derive the value added.

### *5.1 First Step*

Firstly, an enterprises defines its current state by filling in a form about selected properties ($e_1, \ldots, e_t$) of the enterprise. Thereby types of enterprises can be formed, which are comparable regarding the importance of business processes and determining requirements for the IT support for them. Illustrative characteristics could be order confirmation (production with “stock”, production only upon “order” etc.), company’s strategic direction (regional, national, international etc.) or number of employees (cp. Fig. 4).

### *5.2 Second Step*

During the second step the enterprise selects its current state of IT support in business processes. This selection is based on the factual model M and its functional characteristics $m_1, \ldots, m_n$. The functional characteristics are based on different common IT product description levels like e. g. integration, efficiency, flexibility and security (cp. [18, pp. 209–214]).

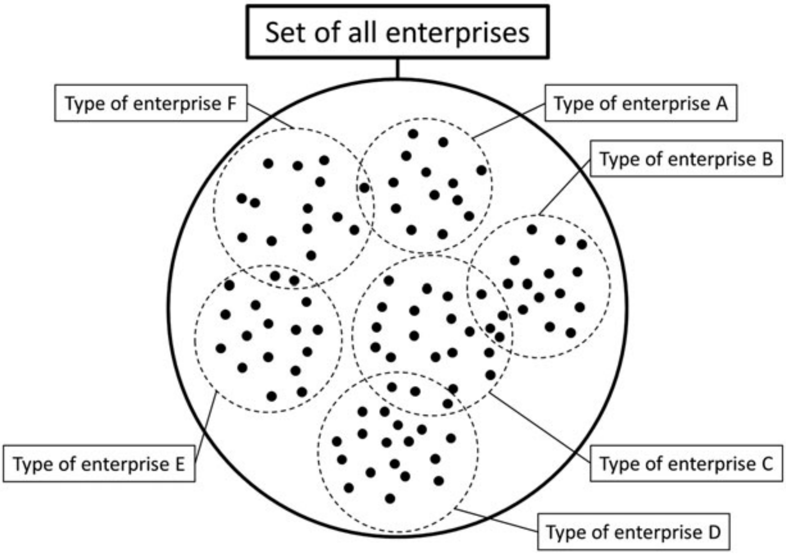


**Fig. 4** First step of the procedure model to evaluate value proposition of IT – defining enterprise types

To create figures for comparison and thus for a later evaluation key figures $(Kz_1, \ldots, Kz_p)$ are gathered for measuring IT support in the specific business process. Those key figures could be e. g. time, quality and costs. They also add up to the average key figures of the specific business process in the enterprise type (cp. Fig. 5).

### *5.3 Third Step*

The third step finally is the evaluation of the current IT support thus quantifying the value proposition of IT. This is done by comparing the own key figures $(Kz_1, \ldots, Kz_p)$ of a specific business process with those average key figures of the business process of the same enterprise type $(Ms_1, \ldots, Ms_j)$. The actual value is the positive or negative difference to the average. Having the additionally gathered information about the current standard of IT support based on the factual model M and the functional characteristics $m_1, \ldots, m_n$, the enterprise can derive decisions regarding investments into their current IT (cp. Fig. 6).

## 6 Conclusion and Further Research

Motivated by the fundamental problem of quantifying the value proposition of IT for investment decisions the relationship between the enterprise and its IT department was described. Due to the evolutionary dependency of the two systems IT department

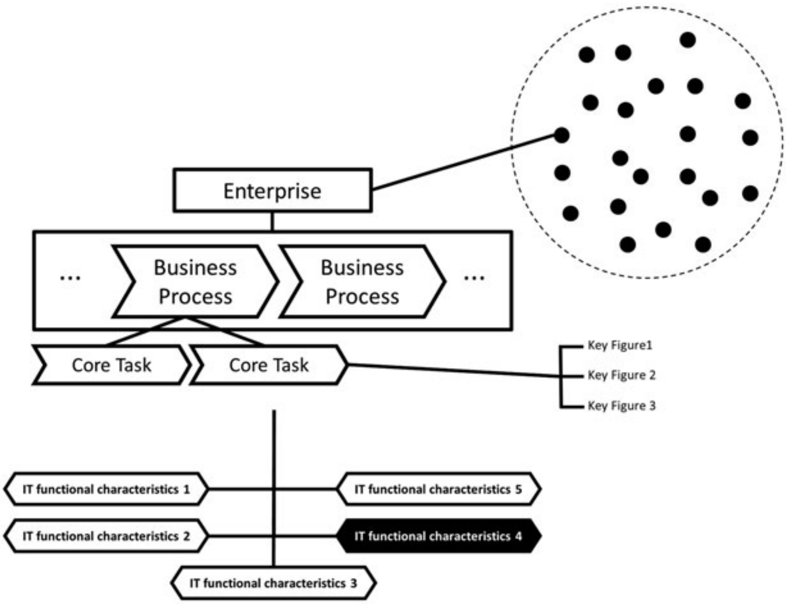


**Fig. 5** Second step of the procedure model to evaluate value proposition of IT – defining IT support

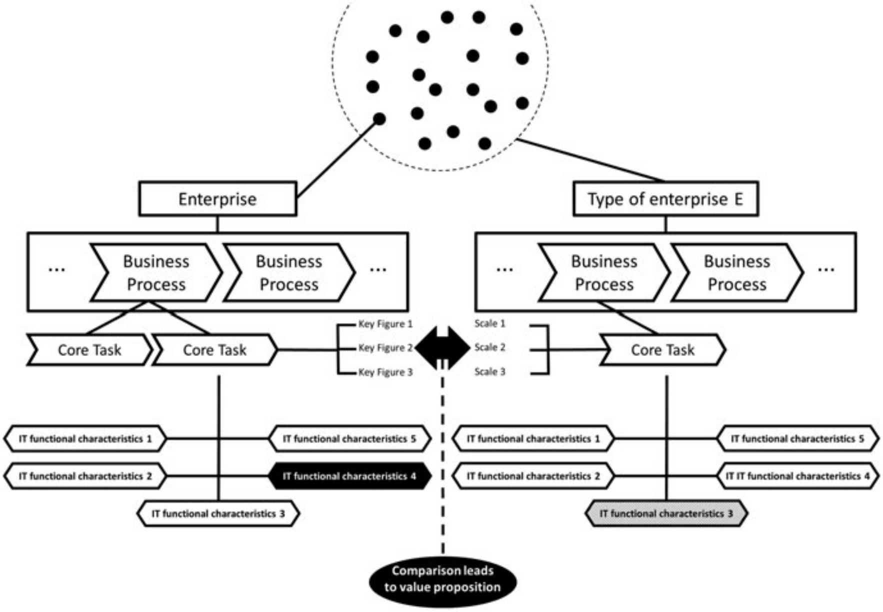


**Fig. 6** Third step of the procedure model to evaluate value proposition of IT – evaluating IT support

and enterprise the relationship was defined as structurally coupled. This kind of relationship makes it difficult to extract value propositions, because the success of one system depends on the other and vice versa. The difficulty of extracting value propositions in mind, value accumulation in general was described by means of a multidimensional model. Further on, the formation of value was defined in a structural model based on the factual and the value level. To create a theoretical solution for the given problem the structural model was further differentiated and preconditions for a practical application were formulated. By outlining a procedure model based on an industry benchmark a way of practical application to quantify the value proposition of IT was proposed.

Further research has to be done on resolving the preconditions. That means properties of enterprises have to be defined, which categorize the enterprises by means of typical IT characteristics. As the procedure model has already proposed this should be done on the basis of an industrial sector. Usually within the sector are the competitors, which an enterprise wants to compare itself with. But as the structural model of value formation also implies the objective and situation should be the same. So it does make sense to reduce the amount of participating enterprises to a specific cultural and economic area for a first practical application. Typically enterprises are organized in area specific associations, which must act as a neutral and trustful entity to collect the data and add it up to create the enterprise type specific IT standard for comparison. The industrial sector should also be the starting point for the creation of the factual model describing IT products on their functional characteristics and the determination of productivity capturing indicators.

The authors are working together with the German Mechanical Engineering Association (Verband Deutscher Maschinen- und Anlagenbauer = VDMA) on the implementation of the proposed methodology. The practical application will be performed in the future among the association members according to the procedure model. This application will also evaluate the benefit of the enterprise type specific scale, which is used as the information basis for comparison.

Furthermore, the differentiated structural model of value formation and its usefulness for supporting decisions in general must be evaluated by the application to a different problem area. It could also be used in change projects to identify important information, which should be given to affected employees, in a structured manner. In this situation the model is used the other way round looking for an answer to the question: Which information does the subject need in order to get a positive evaluation result regarding the object (representing the result of a change project)?

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# Part V
# Semantic Networks and Ontologies for Complex Value Chains and Virtual Environments

# Visualization

**Thomas Beer and Tobias Meisen**

**Abstract** Visualizations in general serve as a decent means to support human communication and inter-disciplinary discussions. In simulations, they are a mandatory component for an efficient and purposeful analysis, in particular. This is the case, because generic computational methods can rarely exploit or detect the simulated phenomena, automatically. Even if so in rare occasions, a visual representation of the analysis results is desirable and necessary for the analyst. Thus, in general, each simulation tool has manifold possibilities to visualize the simulation results and to support the data exploration process.

When using linked tools to simulate the material behavior within manufacturing processes, the exploration process comprises several disciplines and domain experts. Hence, a visualization has to, on the one hand, consider the type of visualization typical for the specific domain as well as, on the other hand, form a contiguous comprehensive representation of the material's state during each time step of the modeled process. This does not only involve multiple scales, but also different temporal and spatial resolutions as well as different kinds of data. This raises several questions that common visualizations do not address. Within this chapter, we give answers regarding questions like "how to handle such process data in visualization" or "how to use such integrated visualizations".

**Keywords** Linked Simulations · Visualization · Data Exploration · Visual Analytics

## 1 Motivation

The ultimate goal of performing simulations in general and linked simulations in particular is a deeper understanding of the underlying processes and effects. Efficient means of data analysis thus are a mandatory component in the overall workflow of

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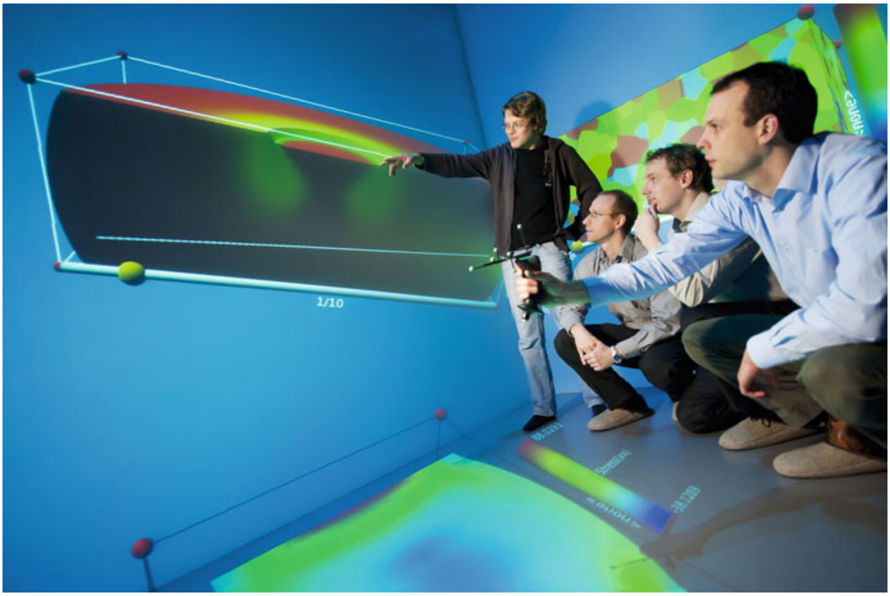



**Fig. 1** Collaborative visualization session inside an immersive virtual reality system, showing results from the gearing component testcase [1]

an ICME-platform. The simulated phenomena can rarely be exploited/detected by generic computational methods. Even in cases in which such detection is possible, a visual representation of detection results is highly desirable. Mere and raw numerical output of any kind in general is only graspable for a very small group of domain experts. Regarding the nature of ICME, several disciplines are involved, which are linked as a composite to describe material's behavior. Interdisciplinary communication across domain boundaries is a crucial ingredient of any kind of successful integrative work. Besides its main purpose – the transformation of pure numbers into visual perceivable information –, visualizations also serve as a decent means to support human communication and inter-disciplinary discussions, as they provide a common basis to which all participants can refer. Common understanding can be achieved much easier, as compared to written or oral communication. The latter often draw on terms that are defined differently in different disciplines, visualization allows to avoid such misinterpretations at a very early stage (Fig. 1).

Apart from the fact that visualizations are needed to get a glimpse of phenomena that cannot be analyzed by automatic algorithms, visualizations that point out those phenomena in a fully automated way cannot be generated. All simulation results originating from an integrated simulation workflow – as explained in the previous chapter –, form a contiguous comprehensive representation of the material's state during each time step of the modeled process. Visualization data have to be extracted for each of these different steps and, subsequent to the extraction, have to be merged into a common visualization context. This context not only involves multiple scales, but also different temporal and spatial resolutions as well as different kinds of data fields (e.g. continuous temperatures at the macro level, discrete grain identifiers at the micro level). This data 'merging' raises a couple of questions not being addressed by common visualization applications by now. The following sections will describe a number of steps necessary to transform the simulation result data into visualization data. Handling of visualization data with respect to their spatial and temporal relations and technical issues to be overcome to generate interactive visualizations of data will be detailed. The last section gives an outlook for visualization and analysis techniques that will emerge from the integrative visualization approach.

## 2 Standardized Post-processing

The Data Integrator allows all simulation data to be translated into a format suitable for visualization. The common format is the PolyData-format of the widely used Visualization Toolkit software library (VTK) [2]. This allows the use of free post-processing tools like e.g. ParaView [3]. After configuration of the initial simulation chain, the specialist's knowledge is required when preparing data for an integrative visual analysis. Within the post-processing tools e.g. ParaView, standard visualization objects, e.g. object surfaces, cutplanes or isosurfaces can be extracted from each dataset interactively. Up to this point, the flow of work allows for a standardized post-processing and visualization may proceed as known for each individual simulation result data.

For an integrated analysis of all datasets resulting from all distributed simulations of the workflow, a further step is required to prepare these datasets for a visualization in a common context. From the datasets prepared within ParaView (cf. Fig. 2), only surface meshes are exported by now for performance reasons. Driving the complete visualization pipeline in real-time during the integrated analysis process is not yet feasible. Besides performance issues, it is also a memory problem to keep full unstructured volumetric data for all simulations in-core at once on regular workstation-class machines. As a wide range of display systems is targeted (cf. Sect. 3), different amounts of visualization data can be handled interactively – a fact which has to be taken into account for the integrative visualization solution. Although the decimation of meshes is still a big topic in various domains, see [4] as an Introduction, it will not be presented in detail here. To point out the immense influence of a decimation approach on visualization results, a comparison of two different approaches will be shortly outlined in the following. The first one can be traced back to geometric error metrics, as proposed by [5]. Based on the local error that a decimation step produces with respect to the local curvature of the mesh, triangles are iteratively removed from the mesh. From a geometrical point of view, this approach delivers good results, Fig. 3. But as soon as data values assigned to the mesh are affected, the results for a decimated mesh are insufficient, e.g. as the temperature distribution for a given example is only rudimentarily reproduced by the decimated results. Generalizations of such decimation approaches to higher

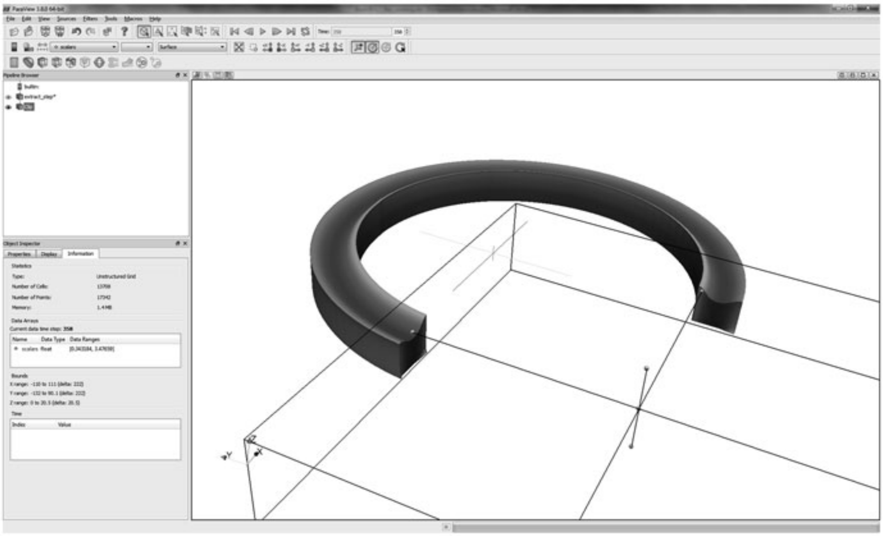


**Fig. 2** Analyzing and preparing a single dataset within ParaView. Shown example: gearing component [1]

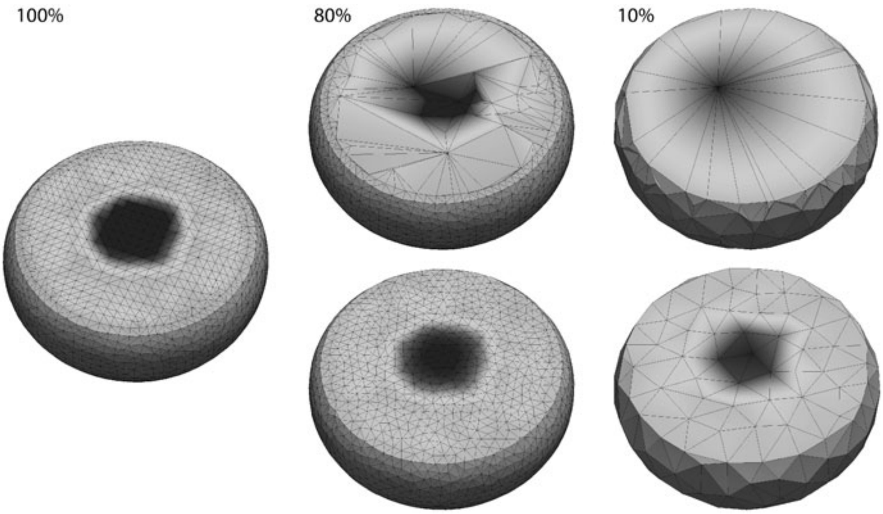



**Fig. 3** Comparing a remeshing (*lower row*) to a coarsening (*upper row*) decimation approach. Shown example: gearing component [1]

dimensionality can be used to include data values in the error metrics, which thus are not restricted only to geometrical errors. The quadrics approach of Hoppe [6] can be regarded as a prominent one. But for practical application of these methods, the additional non-geometric metrics must be defined and their weights have to be chosen,

i. e. how "bad" a deviation of a specific data field (e.g. temperature), introduced by a decimation step, is, compared to other fields or to the geometric errors. This involves a decent amount of domain knowledge with respect to the special semantics that are implied to the data fields by the different simulation models. Thus, a straight-forward quadrics approach is not easily transferable to heterogeneous simulation data.

Representing the principal approach of remeshing, at this point, the work from Valette et al. [7] will exemplarily be outlined. It uses approximated Voronoi cells to create a uniform mesh resolution with either more or less triangles than the original mesh. Such meshes have been used with interpolated data values from the original mesh with sufficient result accuracy. Figure 3 illustrates that this approach can preserve information, e.g. temperature distribution on the surface, which would have been removed by purely geometric based decimation approaches. Although a remeshing takes considerably more time and memory resources (approximately five times in the presented case) as compared to the other methods, it still is a more practical approach than defining special metrics and weights for each different kind of dataset.

The decimated datasets can eventually be used for the integrated visualization of process chains resulting from the defined workflows.

## 3 Integrated Visualization

Integrative and Interactive visual analysis of all result datasets of a simulation scenario is an important part of the integrated simulation approach. Current visualization solutions like e.g. ParaView do not handle all aspects, being required for an integrated analysis yet. Thus a visualization solution has been developed allowing analyzing different datasets in a common context/environment (cf. Fig. 4). To cope with the different kinds of visualization data in a common context, an abstraction layer has been introduced containing meta information about the visualization data, focusing on their spatiotemporal properties according to the simulated process. The different datasets are referenced together with these properties and stored in a simple xml tree. Supported dataset formats in this context include the "ParaView Dataset" format which basically consists of a collection of VTK data files. An appropriate runtime data model provides this information consistently to the different modules of the visualization application and enables them to attach module-specific information for their internal use. This approach allows for a shared data structure but at the same time, by using an approach following the basic idea of role objects [8], no interdependencies between the otherwise independent modules arise, as it would be the case with a naïve shared data structure implementation. Fig. 5 outlines the module structure of the visualization application developed for this purpose.

For an interactive exploration of the simulation results and their temporal relations in the simulated process, a hierarchical organization of the datasets' time frames is used. It is made accessible through a hybrid 2D/3D user interface. All datasets are placed on one or more global timelines. By the interactive manipulation of a dataset's position on a timeline, the visualization session can be dynamically reconfigured as

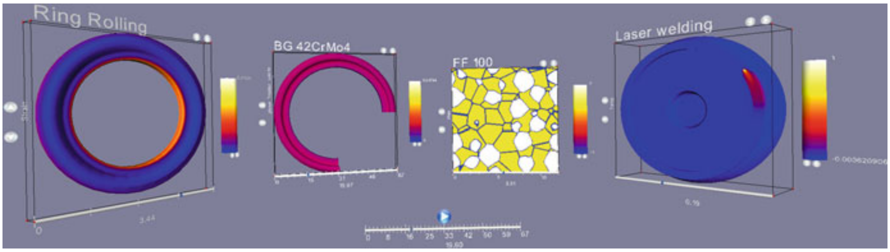



**Fig. 4** Integrated visualization of multiple simulation results. Shown example: gearing component [1]

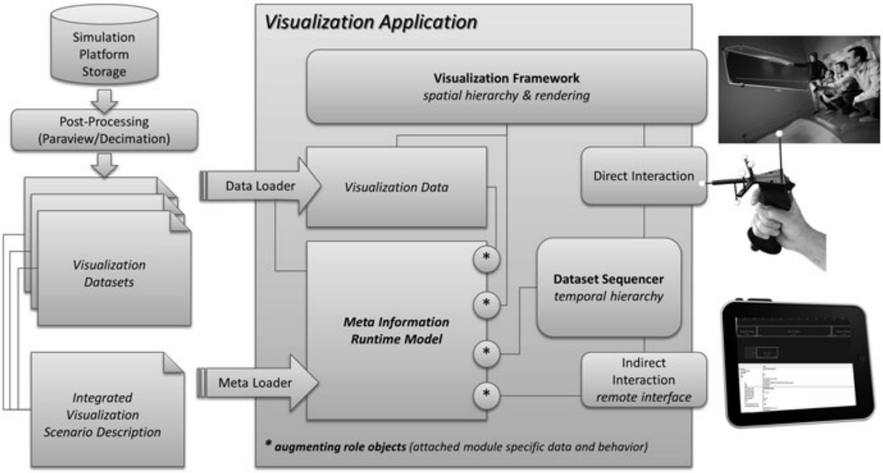



**Fig. 5** Architecture for an integrated visualization application

needed on the fly. This allows for example, starting a visualization session with all datasets aligned on the timeline according to the sequence given by the simulated process. During the analysis process some sub-processes may become interesting and make a side-by-side comparison (in the sense of time) of these datasets more suitable, e.g. to analyze differences in the microstructural behavior during sub-processes (e.g. similar heating steps). The traditional approach to this was to set up a new visualization scenario that includes just these datasets so that they can be analyzed side by side and at the same time. Referring back to the original process then would again require reloading the former visualization scenario and vice-versa. These approaches tend to get annoying and confusing to the user very quickly and are not helpful for concentrating on the analysis process.

To give the analyst more freedom in the analysis process, the present solution is capable of dynamically changing these temporal relations between the datasets, i. e. each datasets position on the timeline, on the fly and interactively through a special

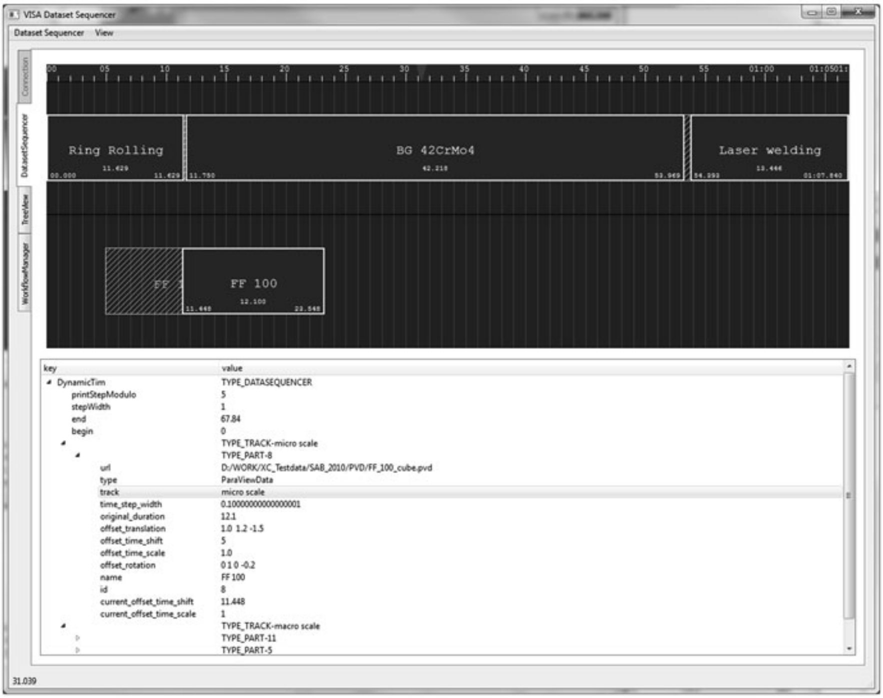



**Fig. 6** The employed interaction metaphor on top of the *Dataset Sequencer*: Intuitive user interface for manipulation of the chronological configuration of a visualization scenario

user interface. This *Dataset Sequencer* tries to follow interaction metaphors found in digital audio/video workstations and adapts them to the field of interactive data visualization.

In the *Dataset Sequencer* each sub-process is represented by a rectangular object spanning its current lifetime on the global timeline, Fig. 6. By interactively moving or resizing the object, the corresponding sub-process will be visualized during a different interval of the global time. To provide the user with information about the original temporal relations of the different sub-processes, their original time is displayed in the background. Additionally, multiple tracks allow for the management of overlapping sub-processes, like simulations on different scales that represent the same time interval of the simulated process. Thus, the temporal aspects of the visualization context can be manipulated interactively in an intuitive manner. The overall visualization solution is designed to be operated on systems ranging from notebooks to high-end distributed immersive Virtual Reality hardware architectures, Fig. 1. According to the heterogeneity of the considered visualization hardware, the user interface can either be used remotely, drawing on e.g. a separate portable device

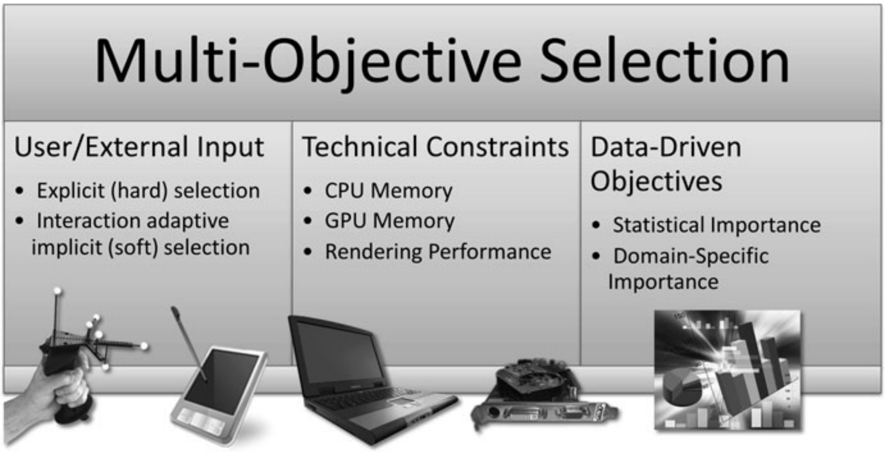



**Fig. 7** Multiple competing selection objectives

when standing inside or in front of a large Virtual Reality system, or as a local application on a desktop system along with the actual visualization. For more details about internals of the *Dataset Sequencer* the interested reader is referred to [9].

As the aggregated visualization data from a simulated process chain easily leads to overload of the hardware of any visualization system, decimation processes and level-of-detail techniques have been incorporated into the visualization solution. These allow for adaptation to the capabilities of the desired visualization system.

The traditional motivation of introducing level-of-detail selection methods is to cope with resource constraints [4]. A more generic methodology for a visualization application would be the selection of "adequate" visualization data from a pool of different temporal and geometrical resolutions of the datasets to be visualized. In this case, one aspect of adequacy could consist in the optimal workload according to the technical constraints of the current display system. This would basically resemble the traditional resource-driven selection approach. Another aspect could be the adaption of the visualization to the displayed data, i. e. to focus on "important" parts. Consequently, combining different metrics of adequacy could result in a balanced selection of data, providing adequacy in terms of both, technical resource usage and a high degree of "important" information. However, evaluating the "importance" of a single part of visualization data is highly specific for each discipline/domain. Different examples of domain-specific data analysis, e.g. [10], and more generic approaches based on information theory, like [11], are known from the field of scientific visualization. Balancing multiple objectives for optimal solutions is a very broad theoretical field and is applicable to many heterogeneous domains. Furthermore, it is still a field of active research since decades. A review of generic optimization methods for engineering application has been published by Marler and Arora [12]. In Fig. 7 the competing classes of selection criteria are sketched.

Besides the multi-objective optimization problem, a further issue consists in the definition and implementation of domain-specific metrics. An example of such a metric could be based on differently evolving temperatures inside an object. In this case, microstructural evolution will most probably be influenced and thus those parts of the simulation data where temperature is not evolving homogeneously could be considered to be "important" by this metric. Regarding the computational and the memory load, as already discussed above, it is not feasible to evaluate such a metric for the entire simulated process chain online during the analysis process. However, in practice, many of these phenomena are closely related to the object's geometry, making it possible to manually define a small number of representative points-of-interest for an object, at which these parameters shall be monitored. The next section describes how such points can be tracked offline throughout the data of a simulated process chain, as a pre-processing step to the visual analysis. From these traces, data values at the selected points can be analyzed efficiently and thus can be considered in the runtime selection algorithm of the visual analysis application.

The main purpose of visualization is to provide its user with information. Thus, besides technical and data-driven metrics, the user plays an important role in the visualization process. Implementations of such user assistance mechanisms always should consider the user as being the central part of the visual analysis process. Accordingly, the user must be able to override or manipulate the assistance process in a way that makes it possible to intuitively navigate the visualization into a user-defined state.

## 4 Data History Tracking

The tracking of data along the entire simulation process is one major advantage becoming possible in the wake of a homogeneous representation of the data. Besides the application, integration and presentation layer, the platform also has an analysis layer containing methods to realize a data history tracking. Data history tracking is defined as the possibility to track data of an arbitrary time and space within the simulation process. In a very simple simulation process, a remeshing of the mesh, representing the simulated assembly, is not required. Hence, the data history tracking is realized by tracking the unique identifiers of each node and each element of the mesh. In contrast to simple simulation processes, complex ones including e.g. the simulation of forming often result in the necessity of remeshing during the simulation process. In such a case, a mere tracking of the identifiers is not sufficient. In fact, it is necessary to identify a mapping between nodes and elements before the remeshing as well as afterwards. Detecting such a mapping requires additional information that has to be provided by the remeshing tool. Presently, the implemented data history tracking method can handle two kinds of such additional information (cf. Fig. 8).

In case of alternative A being processed, it can be translated to a problem presented as alternative B. The translation requires a generation of the displacement table by calculating the vector difference of each node coordinate in the source and the

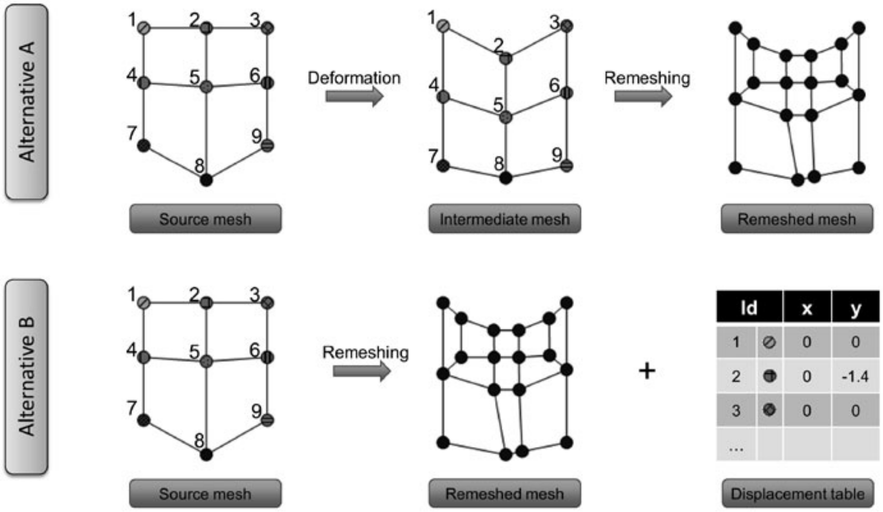



**Fig. 8** Supported alternatives of information about remeshing

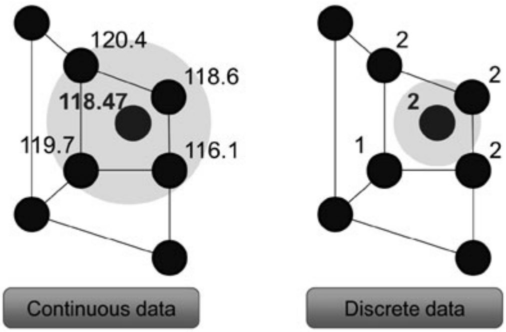
intermediate meshes. By doing so, each node of the source mesh can be localized as an absolute position in the remeshed mesh. Generally, this position is not represented by a node. Therefore, data, like e.g. the temperature, are calculated by interpolating data from neighboring nodes. These neighbors are determined by using the R*-tree index structure [13]. This data driven index structure is optimized for spatial access methods like range or nearest-neighbor queries (NN-queries). The index is generated using minimum bounding rectangles.

By interpolating data for a position, the data history tracking algorithm considers different types of data. For example, temperature information can be interpolated by calculating the average temperature from neighboring nodes. On the contrary, information about the material has to be one element out of a fixed set of existing materials. Hence, different strategies for the determination of an interpolated value are implemented. The algorithm determines the strategy for each type of data using information stored in the knowledge base of the information system. The strategies for continuous and discrete data are exemplarily depicted in Fig. 9.

As presented above, the strategy for continuous data considers a configurable number of nearest neighbors and determines the specific value by weighting the values of the nearest neighbor. The weighting takes the distance between the position and the nearest neighbor into account and is defined by the reciprocal of the ratio between this distance and the total distance. The total distance is the sum of all distances. In case of discrete data, the value is set to be equal to the value of the nearest neighbor.

Displaying such point traces provides the possibility to the user to analyze how material has moved throughout the simulated object during the simulated process. This can be used e.g. to analyze which temperature-time profiles an area of material

**Fig. 9** Strategies for continuous and discrete data




has been exposed to. For the expert this information can serve as an indicator for critical parts of the process like e.g. the probability of phase changes that need to be investigated in more detail e.g. on the microstructural level. Furthermore, if those kinds of metrics can be described programmatically, the visualization solution could use them to determine important parts that then should less likely be dropped but shown in the highest resolution technically possible during the visual analysis process. Extending this approach to the integration module (cf. chapter by Wolters et al., this volume) will help to extract even more optimized and contiguous visualization datasets in the future.

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# Performance Indicators for Factory Planning on the Basis of the Virtual Production Intelligence Approach

**Christian Büscher, Max Hoffmann, Rudolf Reinhard, Daniel Schilberg and Sabina Jeschke**

**Abstract** Production companies in high-wage countries face growing complexity in their production conditions due to increasing variance and shorter product lifecycles. Solutions that provide an integrated view of the planning processes are needed to achieve increasing production quality and efficiency. One approach for managing this complexity is the use of simulation applications to design digital models. Using the approach of "Virtual Production", e. g. factory planning scenarios can be evaluated in advance by simulation. A new integrative concept called Virtual Production Intelligence (VPI) has been developed that applies solutions of different intelligence approaches to the field of virtual production by means of integration and analysis of data aggregated along the simulated processes. In this paper, performance indicators are presented for monitoring factory planning processes using the VPI approach. Hence, critical stages can be simulated in advance to support factory planning projects.

**Keywords** Virtual Production Intelligence · Digital Factory · Factory Planning · Performance Indicators · Data Warehousing · Decision Support

## 1 Introduction

Today, one of the most challenging tasks for manufacturers in high-wage countries consists in attaining high quality products despite the complexity of production processes and the large number of production parameters [1]. Production processes must be continuously optimized in order to achieve a better understanding of the underlying processes and to determine the dependencies of process parameters on quality and productivity criteria. Furthermore, the planning of production processes is complicated by the fact that the required knowledge is dispersed among experts from different fields working on various aspects of the planning process, often at the same time.

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In order to overcome these complexities in the economic environment of continuous globalization and networking, so-called core competencies increasingly matter within modern factory planning scenarios. These competencies include leadership positions in the minimization of costs, quality management and individual attention regarding the interests of clients [2]. The training and the application of these core competencies within the factory planning process make a significant contribution to the "competitive strategy" of modern enterprises [3]. Besides the classic guide to the systematic factory planning, such as adequately described by [4], it is particularly important to create progressive methods of cost- and resource-efficient planning and product development, which also allow a custom and modular design of the planning process. This requires both, a quantitatively founded decision support within the planning process through an integrated picture of the planning process in the overall context of the factory or production facility (see e. g. [5, 6]) and an IT-based analysis by means of the data and parameter variety [7, 8].

In current practice of factory planning processes, in particular the knowledge of experts takes a crucial position. Based on heuristics, existing solutions are tailored and optimized towards a specific application according to qualitative evaluation criteria [9]. However, the knowledge of previous planning processes is generally based on independently developed solutions [10]. A quantitative evaluation of the success of planning and a systematic decision support during the planning process are not sufficiently realized under these circumstances.

An effective approach to the realization of such a support tool is based on business intelligence concepts. These generally have the task to collect and process information in order to gain a deeper understanding of the processes in enterprises [11]. In the context of factory and production planning, the aim of intelligence systems is to "intelligently" process historical data and to provide it to the factory planners in an appropriate way [7]. To enable the transformation of large amounts of data in a structured information model, the existing individual solutions of simulations of factory or production processes are linked together in such a way that interdependencies can be identified and considered between individual planning modules [12]. Therefore, the use of simulation applications in the field of production technology has gained importance in recent years. The term "Virtual Production" encompasses this and other uses of digital models in the context of the "Digital Factory". Virtual production is defined as "the simulated networked planning and control of production processes with the aid of digital models. It serves to optimize production systems and allows a flexible adaptation of the process design prior to prototype realization" [13, 14].

The simulation of single aspects of production, such as process times, can now be examined with relative ease using virtual production simulation applications. However, since different file formats and file structures were independently developed to describe digital models of various processes, the integrative simulation of complex production processes remains as the main challenge [15]. An integrative approach to overcome the interface problem between heterogeneous, distributed simulations is presented with the so-called "Adaptive Information Integration" that is used to realize the "Virtual Production Intelligence" (VPI) [11, 16]. VPI applies solutions of different intelligence approaches to the field of virtual production by means of integration and analysis of data aggregated along the simulated processes. Based on this, the VPI approach provides the possibility of an integrated monitoring of the characteristics of a factory planning or production process and its decision support by consolidated performance indicators or even performance measurement systems.

This paper introduces some performance indicators for factory planning based on the Virtual Production Intelligence approach. After presenting related work of virtual production, modern factory planning and the use of performance indicators in production, the VPI concept is presented. Both the general concept and the application in factory planning are described. Based on this, three performance indicators within the scope of factory planning are exemplarily introduced and discussed on the basis of the VPI approach. The paper concludes with a short summary and an outlook to future work.

## 2 Related Work

### *2.1 Virtual Production and Business Intelligence*

The virtual production aims for an entire mapping of the product as well as of the production within a digital model for experimental purposes. Thereby, the mapping should comprise the whole lifecycle of a product, of a production system or of a factory [17]. The demanded possibilities for analysis serve the purpose of gaining knowledge by examining already completed planning processes in terms of simulation applications. The term "intelligence" is commonly used to describe activities that are linked to those analyses [18]. Software tools, which support the analysis and the interpretation of business data, are subsumed under the term "Business Intelligence".

A common feature of business intelligence solutions is the aggregation of relevant data from different data sources, which are applications within a company, into central data storages [7, 18, 19]. The transmission of data taken from the application data bases into this central data storage is realized by the well-known Extract-Transform-Load process (ETL). Subsequently, the data are arranged in multidimensional data cubes following a logical order. In doing so, a company's IT is divided into two different categories [11]:

- **Operational**: This category contains applications customized for e. g. the accounting department, the purchasing department or the production department of a company.
- **Analytical**: In this case, the category contains applications for the analysis of data arising from the applications mentioned in the operational category.

In order to establish well-founded decision support systems, interconnections between the analytical and the operational parts of an enterprise are needed. Requirements for a system that supports the planning process, in particular the data and application integration, and which follows the idea of intelligence applications such as Business Process Intelligence or Process Mining can be subsumed as below [11, 19]:

- **Interoperability**: Enabling the interoperability between applications in use.
- **Analytical abilities**: Systematic analyses providing the recognition of potentials towards optimization and delivering fundamental facts for decision support.
- **Alternative representation models**: Taylor made visualization for the addressed target groups, which provides appropriate analysis facilities based on a uniform information model.

Therefore, database systems represent a necessary tool for the operational information supply in companies. The objective of database systems is to allow the user a structured data management and an efficient data access [20]. In the classical sense, in this context, databases were mainly required for the storage of data that are necessary for the company's procedures. Since the collected data are usually generated based on heterogeneous systems, an appropriate structure is required in order to store the data in an integrative way. The concept of data warehousing provides this functionality. The founder of the data warehouse concept Inmon [21] characterizes a data warehouse system as a *topic-oriented*, *integrated*, *time-related* and *non-volatile* database to support management decisions. Special emphasis is placed on the property *integrated*. *Integration* is the functionality and the powerfulness to associate and to reconcile data from different operational databases [20]. These features provide data warehouse systems the ability to manage large amounts of data from heterogeneous or even incompatible systems into a unified structure.

## *2.2 Factory Planning*

Manufacturing of products currently takes place in highly complex, networked production systems [22]. Every company can contribute to the creation of the product with one or more sites (factories). Factories can also be seen as networks of different functional units and resources (machines, working places) [22]. Resources, from material to workers, are the smallest distinguishable participants in value creation and are influenced by several parameters and properties that affect the operations.

Factory planning is a systematic process, which is mainly characterized by a high degree of expertise in each of its planning stages. The basic procedure of the planning process proceeds along a systematic, structured strategy. However, decision-making during a concrete factory planning project – both Greenfield and Brownfield Planning – is often based on specific knowledge of a few experts [23]. This raises two key issues in the systematization of factory and production planning processes: Firstly, only a few approaches exist to carry out a quantitative evaluation of the planning success during the various stages of the factory planning process. Secondly, in practice, the linkages between the individual planning modules are mostly based on qualitative models and on the subjective assessment of factory planners. The strong fragmentation of the planning tasks leads to an absence of transparency regarding

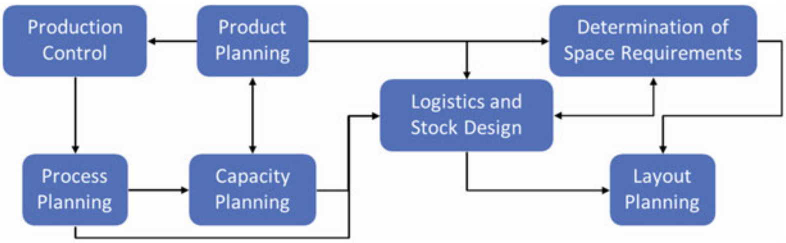



**Fig. 1** Interaction of selected CBFP modules

dependencies among planning tasks. Experts do not know exactly whether or how results influence other planning tasks [23].

Planning tasks are accomplished based on static, predefined assumptions (quantities, products etc.) without knowledge of future changes. Therefore, planning strives to create a production system with maximal production performance (e. g. regarding working speed) to cover all possible future working conditions of the production system. Existing factory planning approaches are based on an analytical and deterministic view, leading to static results. They divide the planning process into linear, sequential, discrete phases. Many similar planning procedures have been published by [10, 24] and others.

To enable quantitative measurability of planning successes, many methods have been developed in the past which allow the simulation of the operations of each production entity in a factory. Such a digitization of production processes means that individual planning modules are fully mapped in a virtual way with defined input and output data. This approach, with the help of which individual planning modules can be optimized, does permit the evaluation of production processes. An advanced approach is the Condition Based Factory Planning (CBFP), which facilitates an efficient planning process without restricting its flexibility by making use of standardized planning modules [23]. The concept of CBFP is employed to analyze factory planning scenarios with the aim of facilitating the factory planning process by decomposing it into single modules [23]. These modules address various aspects within factory planning like material flow or logistics (see Fig. 1). Because of the modular procedure, the characteristically non-linearity of planning processes can be mapped onto each process' modeling. However, a comprehensive review of the planning success in the general context of factory planning is not possible in this approach.

This leads to the second problem mentioned above, the combination of individual planning modules into an overall model. A structured representation of a complete factory planning process can only be realized if interoperability is ensured between the different planning modules. Based on these interfaces, cross-modules can subsequently be identified and finally be integrated into an evaluation of the overall planning project. Due to dependencies between "manipulating variables" in the factory planning, formal quantitative relations can be derived between the evaluations of the individual modules and, in a further step, be formalized in performance indicators. This enables the creation of effective intelligence systems that can act as an effective support tool when making decisions during the planning process.

### *2.3 Performance Indicators in Production Planning*

Performance indicators can be used for planning, management, analysis and monitoring purposes. In this case, the corporate time comparison, the target/actual-comparison and the inter-company comparison (e. g. benchmarking) might serve as applications of performance indicators. Performance indicators gain expressiveness only in conjunction with the company's goals and by the time- or inter-company comparison [25]. This requires a consistent calculation of performance indicators, their consistency, the demarcation of the areas of application and the correct understanding of their information content. The use of performance indicators is limited by the quantification of the operational facts to be displayed. Performance indicators are mainly collected and processed by controlling; furthermore, specific performance indicators such as human resources data or production indicators are generally used in various functional areas [26].

Measures can be taken individually or can be linked to others. Several performance indicators that are logically connected are referred to as a performance measurement system [26]. The question whether the use of single performance indicators or of a performance measurement system is preferred depends on the strategy and the intended use of the indicators of the respective company. Performance measurement systems consist of an ordered set of performance indicators that are related to each other. Performance indicators can, on the one hand, be linked mathematically (computing systems) and, on the other hand, be assigned to issues (classification systems). The interaction of performance indicators as a system will only be possible if they are coordinated from a single position [26].

Performance indicators and performance measurement systems attract interest and are widely applied in the literature as well as in practice. Against the background of growing importance of qualitative variables and their mapping and integration in planning and control processes, they are increasingly used in terms of performance management, that is the holistic approach of quantitative and qualitative variables [25]. The basis of a "Corporate Performance Management" is the interaction of strategic goals as well as strategic and process performance indicators to monitor and control the performance of the corresponding business process [19]. Especially because of the growing importance of quantitative indicators regarding detectable sizes and the various numbers of opportunities that have been accomplished through technical progress in information and communication technology, the concept of performance indicators is frequently used in production, too. An overview of existing performance measurement systems which are related to specific factory information management models can be found in [27].

# 3 Virtual Production Intelligence (VPI)

## *3.1 Objectives of VPI*

Virtual Production Intelligence is a holistic, integrated concept that is used for the collaborative planning of core processes in the fields of technology (material/machines), product, factory and production planning as well as for the monitoring and control of production and product development [11]:

- **Holistic**: Addressing all sub processes of product development, factory and production plan etc.
- **Integrated**: Supporting the usage and the combination of already existent approaches instead of creating new and further standards.
- **Collaborative**: Considering roles, which are part of the planning process, as well as their communication and delivery processes.

The VPI aims at contributing to the realization of the digital factory. An application that makes use of this approach allows the creation of an integrated information base in a structured way. Such an information base contains the input and output data of different simulations in a structured format [8]. Based on such a structured data management, integrated and efficient data access is possible, e. g. by means of structured query language. Methods and tools for data analyses and evaluation, such as Data Warehousing and OLAP (On-Line Analytical Processing), allow the user a variety of possibilities for manipulation and maintenance of existing data [7].

In order to overcome the complexities of production (planning), it is necessary to transfer the production process into a virtual production environment by creating a platform based on the idea of VPI. This environment is formed by combining knowledge taken from computer science, mathematics, mechanical engineering and materials science with data integration and visualization techniques, knowledge engineering, modeling and numerical simulation. The main goal of the VPI platform comprises the reduction of planning efforts and the increase of planning efficiency during design, setup and control of advanced production processes and high value products.

The concept is evaluated amongst others by the technical implementation of a web-platform, which will serve as a support tool. This platform will serve for planning and support concerns by providing an integrated and explorative analysis in various fields of application. Figure 2 illustrates how the platform is used by various user groups in these fields of application. Within the indicator, the use case "factory planning" is addressed, which is the focus of this publication.

Based on the Condition Based Factory Planning and its planning modules presented in Fig. 1, the concept of Virtual Production Intelligence is being researched within the Cluster of Excellence "Integrative Production Technologies for High-Wage Countries" at RWTH Aachen University.

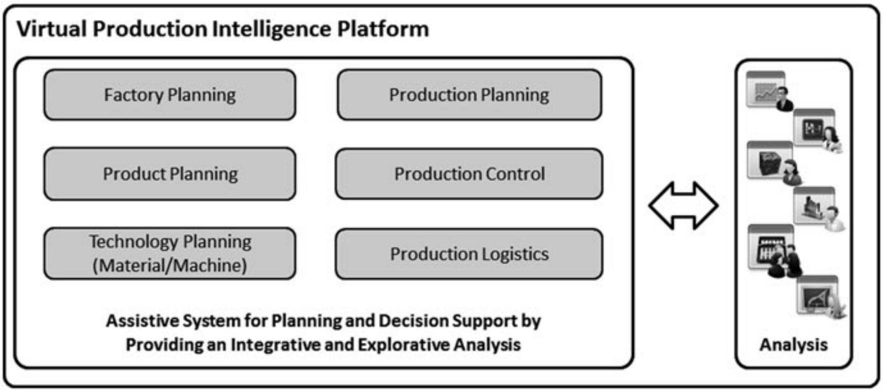



**Fig. 2** The concept of the VPI platform [11]

### *3.2 VPI Application "Factory Planning"*

In a first step, planning tasks will be shared in the factory planning, especially in the areas of product planning, process planning, capacity planning, material flow simulation, layout planning, workplace design and further modules. Within various workshops, requirements concerning the future factory are gathered in collaboration with the customer. For this purpose, table calculation and simulation applications are employed. Thereby, different scenarios of the factory's workload are examined to guarantee the future factory's flexibility. Although the planning process is supported by the planning modules from CBFP, a significant disadvantage remains as the procedure is vulnerable concerning input errors committed by the user. Furthermore, the automated analysis of gathered data is complicated due to the lack of a uniform information model.

The objective of the VPI approach in this application is to support the planning process based on an integrated information model. Thereby, the collection of data is at first performed by making use of familiar applications. Instead of handling single simulation or calculation tools, all data are joined in an integrated model. The implementation of this solution is depicted in Fig. 3.

To utilize the concept of VPI in the field of factory planning, one can use the ability of data warehouse systems to structure large amounts of data in a smart form. In practice, factory planning is often done based on previous planning processes and production data. In order to provide a sufficiently large basis of comparison, a large amount of historical data is needed. The aforementioned advanced simulations of planning processes enable the simplified generation of large amounts of data and data pools. These data only form a specific section of the whole process. In order to implement comprehensive solutions, data from former factory planning processes and data which occur during simulation can be gathered, processed and analyzed by means of intelligence concepts [7]. By making use of data warehouse systems, the

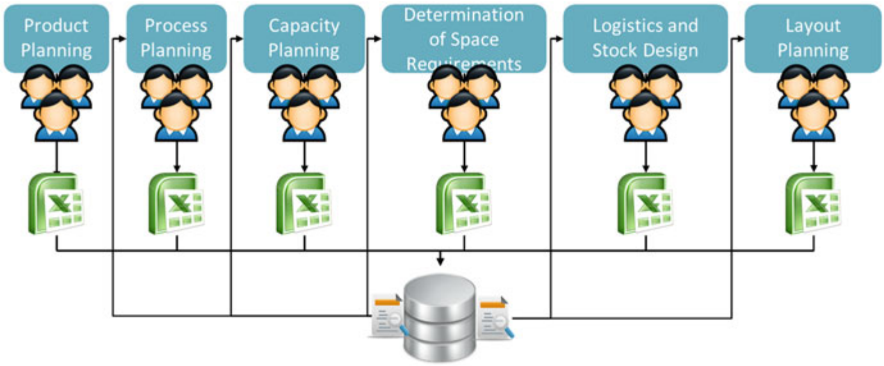
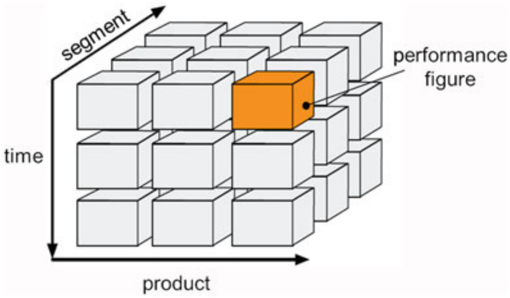



**Fig. 3** Exemplary factory planning process following CBFP and VPI [11]

**Fig. 4** Multidimensional data model for factory planning




simulated processes in combination with the VPI approach thus can be analyzed and optimized with respect to various target criteria on the basis of a multidimensional data model [11]. The added value of the used data warehouse systems is the way to store the results of the different optimization methods. By using dimensions, which e. g. include the parameter settings of an optimization algorithm in the structure, the results of various analytical techniques can be stored in such way that they can be read at any time. In contrast, the quantified part of the model, which is the subject of the analysis, is represented as cells of a cube (facts or performance indicators) whose edges depict the dimensions [20]. An example for a multidimensional data model for factory planning is displayed in Fig. 4.

## 4 Performance Indicators for Factory Planning

Based on the presented application, some variables are chosen in order to develop intelligent performance indicators by means of production systems. Therefore, initially as part of the capacity and process planning, a performance indicator is derived which correlates the customer cycle. Therefore, the target cycle time is specified by the customer cycle in relation to existing respectively planned production resources. Using a second performance indicator, one can assess the work allocation of again existing respectively planned machines to provide an overview on capacity planning. For layout design, a performance indicator is designed to evaluate the surface planning.

## 4.1 Cycle Time

As a part of the process analysis respectively process planning, the customer cycle used within the production structure is transferred to the analysis. The customer cycle (cycle time) specifies how much time t can be spend ideally for a certain task to meet the customer's demand of $N$ products just in time. Thus, the customer cycle expresses how many parts of production are demanded by the customer in a given period. It determines the target cycle time and is expressed in the form:

$$CT = \frac{t}{N} \tag{1}$$

The target cycle time is equal to the customer cycle. A performance indicator that sets the target cycle time $CT_{target}$ measured in relationship to the actual cycle time $CT_{actual}$ is therefore defined as:

$$K_{CT} = \frac{CC}{CT_{actual}} = \frac{CT_{target}}{CT_{actual}} \tag{2}$$

The actual cycle time of a whole product results from the progression of the product along the process chain, beginning with the raw product up to the final inspection and packaging. The whole process time $PT_{total}$ is the sum of $n$ individual process stages $PT_i$ and further unavoidable periods in terms of transport, stock or waiting times $t_{other}$:

$$PT_{total} = \sum_{i=1}^{n} PT_i + \sum t_{other} \tag{3}$$

In order to ensure a delivery to the customer in time, a cycle time performance indicator higher than one is aspired. Therefore, the actual cycle time is less than the target cycle time, which leads to the fact that the real production takes less time than necessary in case of a just in time delivery. Nevertheless, a performance indicator value that ranges far higher than one should be avoided in order to counteract an unnecessarily strong overproduction and inventory increase.

The customer cycle is set within the factory planning concept based on a complex calculation mechanism. It acts as an input variable for the module of the process analysis, but is determined by the module of the production structure. Other variables that provide basic data are e. g. process times, lot sizes, preparation and transport times as well as process chains. These variables are part of different planning modules and are therefore stored in different calculation and simulation tools.

## 4.2 Machine Allocation

Using the considerations of the customer cycle indicator, an additional performance indicator that provides information about the performance and utilization of individual machines in the production process can be defined. The aim of the machine allocation performance indicator $K_{MA}$ is to describe the utilization of a machine during production. The performance indicator should be suitable to carry out an evaluation of the optimization potential of the current production:

$$K_{MA} = \frac{WAT}{t_{available}} \tag{4}$$

When considering machines in general, one has to distinguish between production times and downtimes. Regarding a single machine, this results to the definitions as follows: During process time *PT*, a machine is allocated with the actual production. Furthermore, there are transitional times which include set-up and maintenance times $t_{set-up}$, where the machine is allocated but not free for production. The free time *FT* of the machine includes also waiting times, during which a machine has to wait for the completion of a work step on another machine. Hence, the downtime of the machine contains the transitional and free time. According to these definitions, the work allocation time *WAT* of the machine, during which the machine produces or is in a preparation phase for production, results in:

$$WAT = PT + \sum t_{set-up} = PT + DT - FT \tag{5}$$

To allow a uniform calculation, for both the work allocation time as well as for the definition of the available machine time the same time units have to be used. Using this performance indicator, an objective measure of the utilization of machines during production can be derived. Thus, an evaluation of the general use of the available resources in the production process is possible. The goal is to maximize the machine allocation; the downtime of the machine should therefore be minimized in an optimal organization of production.

In production, the performance indicator is less than one as only the available machine time can be planned. But during the factory planning process, values higher than one are possible in a precise scenario. In such a case, e. g. the available machine time or the number of machines have to be adapted to return to a feasible scenario. Variables needed are again part of different planning modules such as number of items, type and number of machines, the specific production program or the operating model.

## 4.3 Layout Planning

The performance indicator $K_{layout}$, which reflects the current utilization of the area, is defined as follows:

$$K_{layout} = \frac{A_{used}}{A_{available}} \tag{6}$$

To link the area types defined above with the data provided by the factory planning approach, the variables and areas have to be related. According to the determination of space requirements, these variables are the result of the layout planning, especially of the workplace design and the organizational form of production (e. g. workshop, assembly line or central production).

To be able to apply this indicator based on the variables of surface planning, at first, the various types of surfaces are divided into groups. In the context of factory planning, the relevant surface types are therefore defined as follows, taking under consideration that the observation level can vary from the whole factory down to single production segments.

- **Machine area** $A_{machine}$: The sum of the areas that are directly related to the mechanical production and process planning.
- **Storage area** $A_{storage}$: Areas of a factory are not used directly for the production, but have to be available for the storage of finished products in order to meet the demand specified by the customer at any time.
- **Path area** $A_{path}$: Areas where goods, employees or mobile machines are moving. These secondary usable areas as storage areas are not directly associated with the production process, but have to be reserved permanently to guarantee a smooth workflow of logistical operations.
- **Available area** $A_{available}$: The theoretical area of the regarded scope. For the whole factory, it is the factory building which can be used for production (shop floor).
- **Unused area** $A_{unused}$: Areas of the factory which are available, but which are neither related directly nor indirectly to the production. These areas are often used to provide space for possible extensions of the factory or the production.

Hence, the performance indicator can also be presented as follows:

$$K_{layout} = \frac{A_{machine} + A_{storage} + A_{path}}{A_{available}} \tag{7}$$

The proposed performance has a theoretical value between zero and one, while the one represents a coverage of 100 % of the available area. Again, similar to $K_{MA}$, values higher than one are possible. Those values are a sign of relayouting and optimization requirements, which influence not only the layout planning. As the whole available space is predetermined and no allocation for all needed resources with their own dimensional requirements is possible, a replanning of technologies, of the organizational form of production or even of the production program is necessary.

## 4.4 Discussion

The three performance indicators presented above do not intend to represent a holistic view of the factory planning process, but they provide a good profile of important performance indicators along the process chain. Each of the indicators is a reference for the quality of the current planning respectively the final factory planning result. As described before, the data basis for calculating the indicators is very heterogeneous as the variables are part of different planning modules and their simulation tools. Instead of standardizing the data interchange, both the semantic information integration process and the multidimensional data model presented in Sect. 3 can be employed as the basis of the VPI.

This allows a comprehensive data analyses which will be presented in the following by means of the layout planning performance indicator. Regarding Fig. 4, $K_{layout}$ can be analyzed in the dimensions of segment, time and product. The crucial point is that in one element of the data cube, the stored data has to be at the same aggregation level as the lowest aggregation level to be desired. This implies that e. g. the segment structure is based on one production unit. On this basis, an aggregation to a production segment or the whole factory is possible; in contrast, a further subdivision to single working places cannot be executed [20]. A comparable situation arises when analyzing $K_{layout}$ in the dimensions of time and product as well as in the case of analyzing the other performance indicators. Hence, a time based analysis of the machine allocation concerning the production of a specific product in certain segments can be performed. For the first example, the underlying data structure of the data warehouse is shown in Fig. 5.

To readdress this example, since all variables of the surface planning directly refer to the layout plan, $K_{layout}$ can also be used as an evaluation criterion for different views of the factory layout. A potential expansion opportunity for the performance indicator can be lead through a modularization of the different areas in the factory. For a section A, the layout performance indicator can be defined as follows:

$$K_{layout,A} = \frac{A_{machine,A} + A_{storage,A} + A_{path,A}}{A_{available,A}} \tag{8}$$

In this case, previously, an aggregation of the individual surfaces has to be performed regarding their affiliation with the section A. Through this modularization of areas - characterized by the added index A - the methods used to determine the individual sizes change. This can be illustrated e. g. in the calculation of the path areas. While the variable $A_{path}$ includes paths between departments, these have to be dropped when regarding $A_{path,A}$ for section A. In changing the observation level to the whole factory, every single area has to be considered.

Based on the flexible analysis of $K_{layout}$ to individual areas, an optimization of the whole factory can be performed more specifically in contrast to the consideration of the performance indicator of the whole factory. Thus, optimizations performed on the basis of individual sections can e. g. be evaluated with regard to the resulting effect on the overall production.

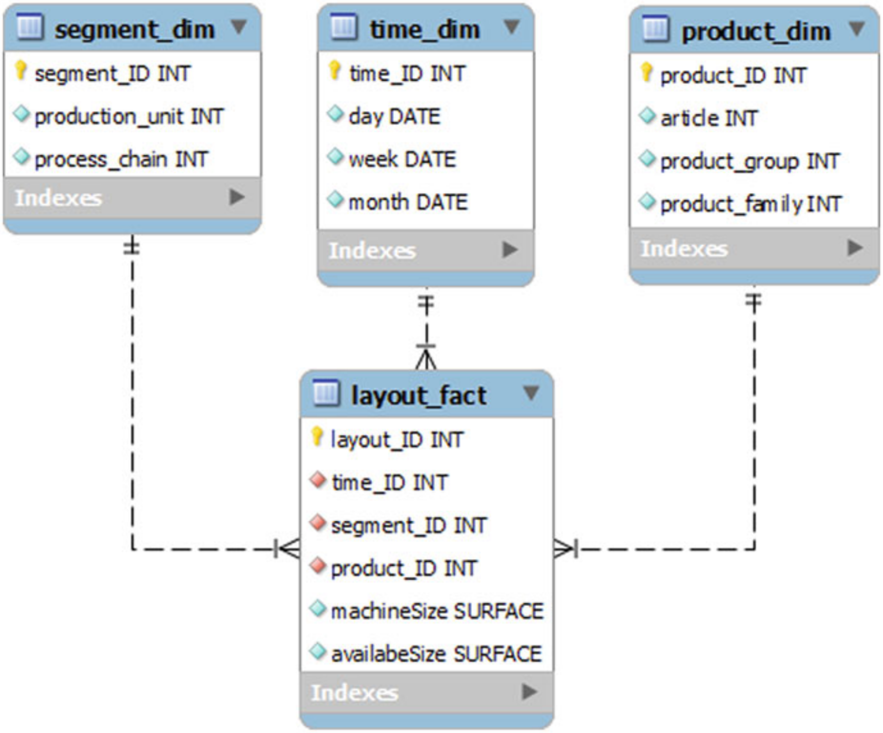



**Fig. 5** Data warehouse structure of the layout performance indicator

Another important dimension, which is not shown in this paper, is the scenario. One of the main planning manners is the use of different planning scenarios, e. g. concerning different customer demands, production or machine settings or even factory buildings. With the presented information model, the scenario dimension can easily be added to analyze and to compare all aspects of the different planning scenarios by means of the performance indicators. Thus, the planner can select one scenario or connect aspects of different scenarios to continue the planning process. Hence, a reduction to single predominant scenarios is possible at an early stage of the planning process, which is an improvement in efficiency and quality compared to the current situation.

## 5 Summary and Outlook

Within this paper, a concept named "Virtual Production Intelligence" (VPI) has been presented, which describes how intelligence solutions developed within several fields can be adapted properly to the one of virtual production. This concept, which is both holistic and integrated, is used for the collaborative planning, monitoring and control of core processes within the field of factory planning.

Furthermore, the data concept for this application domain based on VPI was introduced, followed by the depiction of selected performance indicators to characterize the quality of factory planning scenarios. The combination of such indicators, a multidimensional data model and the VPI approach lead to a significant increase in flexibility of information analysis and evaluation of factory planning. By discussing some aspects, the use of this approach, namely supporting factory planners in their decision-making, was pointed out which leads to an improvement in the whole factory planning process.

In the next steps, the development and implementation of a VPI platform are at first advanced in a research environment but with single industrial applications. Concerning the factory planning aspect, the data warehouse model will be extended and, based on this, a performance measurement system will be developed and visualized in the VPI platform, which contains the presented indicators. Further OLAP algorithms will be generated to improve the decision support provided by VPI.

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# A Modular Factory Planning Approach Based on Vertical Integration of the Information Flow

**Max Hoffmann, Tobias Meisen, Daniel Schilberg and Sabina Jeschke**

**Abstract** The increasing complexity of products and consumer interests is facing more and more challenges to production planning. An innovative approach, which facilitates efficient planning, is represented by a model-based approach using the concept of the Digital Factory. In order to realize the vision of virtual production, modular solutions like simulations or optimization tools are merged into a holistic model that provides a digital mapping of the entire production process. In this work, a framework is described, which is capable to integrate planning modules by using an integrative information model. Based on intelligence approaches, multiple data is linked to reach a vertical integration of the information flow. These cross-linked data structures facilitate a consolidation of data from different levels of the production monitoring and management layers. The provided information is used to establish decision support systems, which enable an entirely holistic factory planning. The advantages of the approach are demonstrated by a process chain formation use case.

**Keywords** Virtual Production Intelligence · Factory Planning · Digital Factory · Data Mining

## 1 Introduction

Due to the rising interests in a higher variety of products, the modularity of the production gains in importance. Thus, necessary modifications of the production structure and their impact to technical and economic aspects have to be taken into consideration during the planning. As the consideration of dependencies in a factory is highly complex, the planning has to be divided into distinctive planning steps. One approach to modularization of the planning was introduced by Schuh et al. [1]. The presented "Condition Based Factory Planning" splits the planning into distinctive modules in order to create more structured and systematic ways of planning. The advantages of such an approach are the determined procedure of planning projects and

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the possibility of splitting the process into working packages, which can be performed by experts. The drawbacks of this approach, however, consist in an insufficient consideration of interdependencies between the planning modules.

Thus, the goal of a holistic factory planning approach consists in the definition of an information model that contains not only the capabilities to integrate the different planning modules of the factory planning process, but also to manage the information generated and provided by various sources. In the present work, a software framework will be introduced that contains an information model, which serves interoperability between the modules of a modular factory planning approach.

## 2 State of the Art

Layout planning has emerged to one of the core elements in factory planning [2] and is carried out in several steps based on different planning modules. According to Guideline VDI 5200 [3], the layout planning is part of the conceptual planning of a factory and is performed firstly by determining the ideal layout. The derivation of the ideal layout is hereby comprised of structure planning and the dimensioning of resources. The ideal layout is initially designed using existing production data before it is adapted to other requirements of the production.

Existing production data or manufacturing information can for instance consist of product lists, processes, quantities and other variables of the Enterprise Resource Planning (ERP). Based on this data, several possible production configurations are selected and compared. Numerous heuristic and graphical methods have been carried out to support the determination of the ideal layout [4]. The considerations of boundary conditions as well as the communication flow are performed in later steps of the planning through the determination of the real layout [2]. A well-structured summary of the different approaches and factors influencing the layout planning is provided by Kampker et al. [5].

The step from the ideal to the real layout is usually influenced by the knowledge of experts as a core element in factory planning. As a consequence, the real layout is mainly shaped through experience values and it is documented in a qualitative and abstract form. Hence, in literature, there is a lack of explicit instructions regarding the compliance of conditions such as ensuring communication flows and the modularity of the production. Similarly, there are only few quantitative approaches for estimating the costs arising from the consideration of the boundary conditions [5]. Accordingly, the main challenge in layout planning is the quantitative measurability of various scenarios with the aim to determine an optimal solution. One approach to systematize the experts' knowledge and experience in the planning process consists in an establishment of Decision Support Systems.

According to Arnott and Pervan [6], Decision Support Systems (DSS) represent an information systems discipline that focusses on supporting and improving managerial decision-making. One of the most important development branches of the DSS central idea consists in the Executive Information Systems (EIS), which can be characterized as data-oriented DSS [7]. In the late nineties, a certain kind of DSS was introduced, which extended the idea of EIS to enterprise-wide reporting systems. These DSS are referred to as Business Intelligence (BI) systems. Due to their data-oriented, enterprise-wide character, BI systems can serve as decision support tools in heterogeneous environments. The underlying Intelligence concepts can be applied either on the economical optimization in a company or within the production environment. In terms of production planning, Intelligence systems are intended to process both historical data from the process and product development as well as real-time data from the production to guarantee data propagation to people, who are involved in the planning process, in an appropriate form [8]. The most important developments in this context consist of Operational Business Intelligence (OpBI) and Manufacturing Execution Systems (MES), which both serve a BI-like decision support within the production environment [9].

A combination of the technologies described above could lead to a flexible layout planning. However, the central problem is the rather unsystematic way factory planning projects are currently performed. In order to realize a more flexible and consequently complex production while keeping the modular factory planning approach, systematic ways of data management have to be carried out.

## 3 Virtual Production Intelligence

The systematic way of planning described above can only be realized through an aggregation of data taken from different planning modules and IT tools into one embedded system. However, the consolidation and propagation of data from different levels and layers of the production is difficult due to the heterogeneity of the underlying information systems. Accordingly, the problem that needs to be solved in this context is to ensure interoperability between information systems used within various methodologies of data generation and data aggregation [10]. In addition, inter-operability has to be established between various modules of the factory planning process as the complexity of the planning is managed by the modularization of the planning into sub-processes.

An integrative solution to serve interoperability between heterogeneous, distributed systems is presented with the adaptive information integration [11]. A framework based on this approach allows the creation of an integrative information model in connection with a common data basis, which contains both input and output data from various applications in a structured form [12]. This framework and the according information model enable an establishment of BI approaches into the domain of virtual production and are referred to as “Virtual Production Intelligence (VPI)”. The VPI allows a merge of heterogeneous planning, simulation and optimization tools. Based on the information model, a platform has been carried out that is capable of integrating information from different corporate and production processes as well as simulations into a common data basis. This multi-dimensional data basis

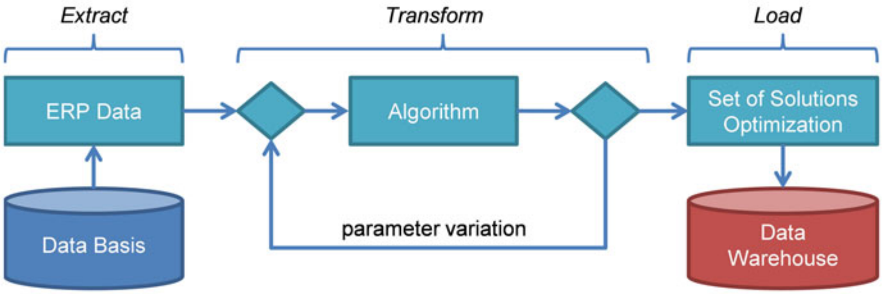


**Fig. 1** Extract-transform-load process in order to perform a multi-dimensional optimization

enables a vertical flow of information from all levels of production management and operations due to the integrative methodology of the information model.

In order to integrate data into the data basis, Extract-Transform-Load (ETL) processes are carried out. In these processes, data has to be extracted from a corresponding application. In a further step, it is transformed in accordance to the information model and finally loaded into a data warehouse system (see Fig. 1). Thus, on the one hand, interoperability is guaranteed, and, on the other hand, the architecture of software systems do not need to be adjusted to be applicable in the overall planning context.

In addition, the framework contains a front-end solution in the form of a web interface. The interface is intended to show the aggregation as well as the user- and role-specific representation of the resulting data generated on the basis of various applications. It provides an end-to-end view of all important data of the planning suitable for the current user. The user can thus make sound and quantitatively reliable decisions concerning the planning progress and is hereby also supported by underlying analysis methodologies that are embedded in the information platform. Based on the interface, cross-module connections in the factory planning can be identified and integrated in the evaluation of the overall project. Due to the detected dependencies between the determining variables, formal, quantitative relations between different planning modules can be derived. This allows the realization of effective intelligence systems, which can serve as a support tool in decision-making during the planning process, thus enabling a more flexible production.

## 4 Use-case Layout Planning

With regard to the ideal layout optimization heuristic approaches are usually applied. The results of such heuristics rely on qualitative estimates, which are then further developed using semi-analytical or iterative mathematical techniques to gain an "optimal" solution of the problem. In layout planning, the procedure is usually designed in a way that the number of segments is defined in advance. According to the requirements of the products to be manufactured, process chains are formed, in which the largest possible number of these products can be mapped.

The issue of this approach is to embed the planning results into the overall workflow of the layout planning. An evaluation of each supply chain configuration with respect to the real layout is usually associated with a high effort as the results of different planning scenarios with different parameters have to be manually entered into further planning tools. An evaluation of all scenarios is thus connected with unreasonable efforts, so that the factory planner usually defines a determined solution before continuing with further optimization steps. This way of determining a fixed solution is problematic as other possible solutions are ignored for the rest of the planning and will not be further evaluated. Therefore, an integrative data basis is needed, which allows for the consideration of all possible configurations within the upcoming planning steps.

Using the Virtual Production Intelligence Platform, possible planning scenarios are transferred and consequently considered in further planning steps. In order to demonstrate the related benefits, an algorithm has been developed, which performs a process chain determination based on historical production data. Similarities and regularities within these chains are identified through quantitative measures that have been implemented based on counting methods, through which an evaluation of the process chains is also performed. The main process chains, which were identified during the assessment, are evaluated using statistical and heuristic methods. Furthermore, they are modified using an iterative optimization algorithm until a determined coverage of the products is guaranteed. The results of the proposed algorithm can be seen as the optimal solution of the production structure configuration – that is the ideal layout – for a specific production list and parameterization.

The algorithm of the process chain optimization tool has been integrated into an Extract-Transform-Load (ETL) process in order to reach a modular storage of the optimization results. The procedure of the process chain optimization has been divided into several steps:

1. The existing production data is loaded from the Enterprise Resource Planning database and is used for the generation of process chains (*Extract*).
2. Then, the algorithm is executed in the *Transform process*.
3. A possible parameter variation can be performed by changing the number of main chains for each optimization run. Consequently, the algorithm is carried out for any specified number of main chains and determines and optimal solution for this specific parameterization.
4. The results of each optimization run are stored in a multidimensional database, hence a Data Warehouse (*Load*), so that the results of each scenario are mapped into the data basis.
5. Through a web-based User Interface, the user receives the results, which are tailored to his corresponding parameter selection (see Fig. 2).

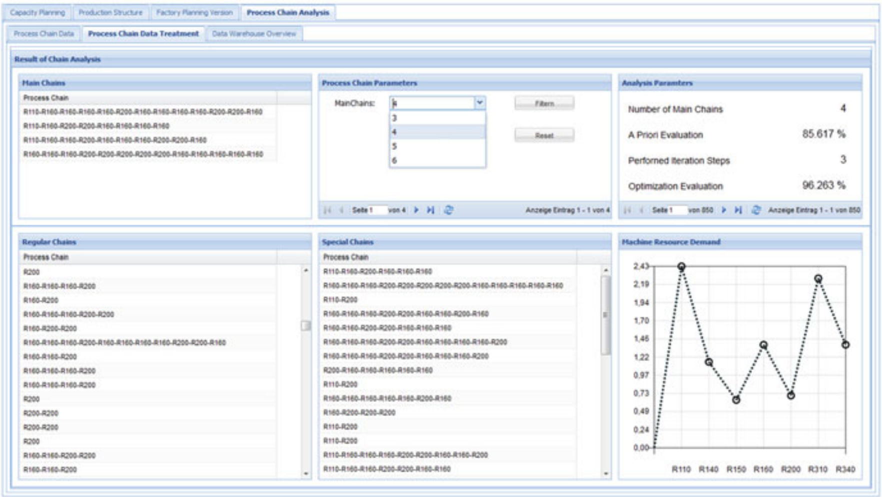


**Fig. 2** User-interface for the management of process chain optimization scenarios

In the top left corner, the main process chains for the selected parameters are shown. In the middle, the user can select parameters out of the relevant parameter range. The upper right corner shows the quantitative results of the optimization. Within this corner, firstly, the chosen parameter is visualized. Secondly, the evaluation before applying the algorithm is pointed out as well as the number of needed iteration steps and the final results of the optimization.

The lower left corner of the web application interface shows the product chains that can be produced using the determined main process chains. The “Special Chains”, which are shown in the middle of the lower part, make up an amount of about 3.7 %. These chains cannot be manufactured using the main process chains without making additional logistical efforts. In the lower right corner, a graph is depicted which shows an example of the current resource demand of the different manufacturing machines, which can also influence the results of further calculation steps.

## 5 Conclusion and Outlook

Based on a use case it was shown that the use of Intelligence concepts – in particular the VPI – result in far reaching benefits in factory planning. Because of the use of the VPI platform, various constraints and parameters can be considered in the planning process. This enables an integrated, holistic view of the various scenarios of a factory planning project so that individual modules of the production planning can be evaluated in the overall context of the planning. Quantitatively reliable and sound statements over the planning success can thus be made at any time.

In the context of optimized production planning, the next steps will consist in expanding the concepts presented both in terms of algorithmic and methodological aspects. In this connection, the process chain term has to be extended in terms of its dimension. The resulting multi-dimensional process chains allow the consideration of temporal constraints between the manufacturing steps of a product and thus provide a holistic mapping of the production structure. Thus, in production, cycle times will be harmonized by a parallel connection of machinery resources and waiting times are minimized. This enables a user configurable, modular design of a multi-variant production.

On the methodological side, the presented concepts of the vertical integration of production data have to be realized by extending the VPI Platform in terms of the data flows from the MES and the field level. These information need to be processed and aggregated automatically so that they are available within the ERP system and production planning. Only through the interoperability between these systems, an integrated digital mapping of the production is possible. This provides the basis of intelligent tools for the planning and decision support in order to ensure a continuous improvement and further development of the production planning process.

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# Dynamische Optimierung der digitalen Produktentwicklung auf Basis cyber-physischer Monitoring-Systeme

**Max Hoffmann, Tobias Meisen, Daniel Schilberg und Sabina Jeschke**

**Zusammenfassung** Die zunehmende Komplexität von Produktionsprozessen stellt immer neue Herausforderungen an die Produktentwicklung. Ein innovativer Ansatz im Sinne einer effizienteren Entwicklung besteht in der Virtualisierung der Planung. Das Konzept der „Digitalen Fabrik“ ermöglicht hierbei eine frühe Beurteilung des Planungserfolgs. Durch Integrationsverfahren können so verschiedenste Simulationsverfahren zu einer Wertschöpfungskette zusammengefasst werden. Im Rahmen der vorliegenden Arbeit wird ein Framework vorgestellt, das die Integration von Daten sowohl aus Simulationen als auch aus der operationalen Ebene auf Basis cyber-physischer Monitoring-Systeme in ein integratives Datenmodell ermöglicht. Die ganzheitliche Abbildung des Produktionsprozesses ermöglicht eine Evaluation des Planungserfolgs bereits in frühen Stadien der Planung. Hierauf basierend können – in Anlehnung an das Konzept der Business Intelligence – Werkzeuge realisiert werden, die den Fabrikplaner bei der fundierten Identifikation von Optimierungspotentialen unterstützen. Der hiermit verbundene Vorteil für den ganzheitlichen Produktionsplanungsprozess wird auf Basis einer Layoutplanung in Verbindung mit einer Prozesskettenoptimierung aufgezeigt.

**Schlüsselwörter** Digitale Fabrik · Business Intelligence · Data Warehousing · Virtual Production Intelligence · Cyber Physical Systems · BI · VPI · CPS

## 1 Einleitung und Motivation

Um sich im wirtschaftlichen Umfeld stetiger Globalisierung und Vernetzung gegenüber einer starken Konkurrenz behaupten zu können, stehen im Rahmen moderner Fabrikplanungsszenarios in zunehmendem Maße sogenannte Schlüsselkompetenzen im Vordergrund. Dazu zählen führende Positionen in der Kostenminimierung, Qualität sowie in der individuellen Beachtung von Kundeninteressen [1]. Die Ausbildung und die Anwendung dieser Kernkompetenzen im Fabrikplanungsprozess

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leisten einen entscheidenden Beitrag zur „konkurrierenden Strategie“ moderner Unternehmen [2].

Neben dem klassischen Leitfaden der systematischen Fabrikplanung [3], müssen vor allem moderne Verfahren der kosten- und ressourcenschonenden Prozess- und Produktentwicklung geschaffen werden, die zudem eine individuelle und modularisierte Gestaltung des Planungsprozesses erlauben. Dies erfordert einerseits eine quantitativ fundierte Unterstützung bei der Entscheidungsfindung innerhalb des Planungsprozesses durch effiziente Intelligence-Lösungen [4] sowie zum anderen eine integrative Abbildung des Planungs- und Produktentwicklungsprozesses im Gesamtkontext der Fabrik [5, 6].

In der gängigen Praxis von Fabrikplanungs- und Produktentwicklungsprozessen nimmt hierbei insbesondere das Wissen von Experten eine entscheidende Position ein. Auf Grundlage von Erfahrungswerten werden zumeist bestehende Lösungen hinsichtlich qualitativer Bewertungskriterien auf einen spezifischen Anwendungsfall zugeschnitten und anschließend optimiert [7]. Bei dieser Vorgehensweise gehen die aus vorangehenden Planungsergebnissen hervorgegangenen Erkenntnisse zwar mit in den Entscheidungsprozess ein, jedoch führt dies zu keiner nachhaltigen Systematik bei der Lösung von Problemen der Produkt- und Prozessgestaltung [8, 9]. Das prinzipielle Vorgehen des Planungsprozesses verläuft somit zwar entlang einer strukturierten Vorgehensweise, die Entscheidungsfindung während eines konkreten Projekts beruht jedoch auf speziellem Expertenwissen und ist daher in der Regel qualitativer Natur.

Daraus ergeben sich zwei zentrale Probleme bei der Systematisierung von Produktionsplanungsprozessen. Zum einen existieren bislang nur wenige Ansätze, um eine quantitative Evaluation des Planungserfolgs während der einzelnen Stufen des Planungsprozesses vornehmen zu können. Zum anderen beruhen die Verknüpfungen der verschiedenen Planungsmodule untereinander in der Praxis zumeist auf qualitativen Modellen bzw. auf der subjektiven Einschätzungen der am Planungsprozess beteiligten Akteure. Eine quantitative Evaluation des Planungserfolgs sowie eine systematische Unterstützung bei Entscheidungen während des Planungsprozesses sind somit nicht realisierbar.

Ein wirksamer Ansatz zur Realisierung aktiver Unterstützungswerkzeuge beruht auf den sogenannten Intelligence Konzepten. Diese – an das Konzept der Business Intelligence (BI) angelehnten – Systeme haben im Allgemeinen die Aufgabe, Informationen zu sammeln und aufzubereiten mit dem Zweck, ein tieferes Verständnis der Abläufe in Unternehmen zu erlangen. Im Rahmen der Produktionsplanung haben diese Intelligence Systeme die Aufgabe, sowohl historische Daten aus der Prozess- und Produktentwicklung als auch Echtzeitdaten aus der Produktion strukturiert aufzubereiten und den an der Planung beteiligten Akteuren in geeigneter Form zur Verfügung zu stellen [4].

Die strukturierte Aufbereitung und Bereitstellung der notwendigen Daten erfordert es oftmals, Daten aus heterogenen Anwendungen zusammenzuführen. So wurden in der Vergangenheit zahlreiche Verfahren entwickelt, mit denen sich die Arbeitsvorgänge einzelner Produktionsentitäten in einer Fabrik simulieren lassen.

Bei einer derartigen Digitalisierung von Produktionsschritten fallen Daten unterschiedlichsten Formats und Ausprägung an. Durch die Einführung neuartiger Systeme, wie im Kontext der *Cyber Physical Systems* in Verbindung mit einer vernetzten Infrastruktur im Sinne des *Internet of Things* diskutiert, werden außerdem zunehmend Produktionsdaten in großer Menge und Vielfalt durch die Produktionsanlagen selbst generiert.

Eine Aggregation dieser Daten in Verbindung mit Simulationsdaten und sogenannten historischen Produktionsdaten kann unter anderem dazu verwendet werden, die Layoutplanung einer Fabrik in einem hohen Detaillierungsgrad digital abzubilden. Verschiedene so gebildete Produktionssegmente können einem quantitativen Vergleich unterzogen werden. Dies führt zu belastbaren Ergebnissen sowie zu einer aktiven Entscheidungsunterstützung während des Produktionsplanungsprozesses.

Vor diesem Hintergrund besteht die erste zu lösende Herausforderung darin, eine Interoperabilität zwischen den IT-Systemen, die bei den verschiedenen Verfahren der Datengenerierung und Datenaggregation zum Einsatz kommen, zu gewährleisten. Desweiteren muss eine Interoperabilität nicht nur zwischen Simulationen, sondern außerdem zwischen den verschiedenen Planungsmodulen des Fabrikplanungsprozesses geschaffen werden, damit einzelne Optimierungsverfahren zu einem Gesamtmodell der Fabrik und somit zu einer Evaluation des gesamten Planungsprojekts aggregiert werden können. Damit lässt sich zum Beispiel das Layout einer Fabrik mit hinreichender Genauigkeit digital abbilden und optimieren. Eine Einbettung der hieraus resultierenden Bewertung in den Gesamtkontext der Fabrik ist darauf basierend jedoch noch nicht ohne weiteres möglich. Eine Bewertung des Planungserfolgs kann daher erst nach weitreichender Fortführung des Planungsprozesses erfolgen, was mit einem hohen planerischen Aufwand verbunden ist.

Eine integrative Lösung zur Schaffung von Interoperabilität zwischen heterogenen, verteilten Simulationen wurde im Rahmen vorangehender Publikationen mit der adaptiven Informationsintegration vorgestellt. Ein hierauf basierendes Framework ermöglicht die Schaffung einer integrierten Datenbasis, die die Ein- und Ausgangsdaten verschiedenster Simulationen in strukturierter Form beinhaltet [10]. Diese Datenbasis liefert die Grundlage für die Etablierung einer „Virtual Production Intelligence“, in der grundlegende Konzepte von Intelligence-Lösungen in die Domäne der virtuellen Produktion übertragen werden. über eine Web-Schnittstelle ist neben einfachem Zugriff auf den integrierten Datenbestand auch dessen Auswertung und Analyse auf Basis von Heuristiken und anderen Verfahren der Informationstechnik, zum Beispiel mittels Data oder Text Mining, möglich.

Auf Basis dieser Schnittstelle lassen sich in der Folge modulübergreifende Zusammenhänge in der Produktionsplanung identifizieren und in eine Evaluation des gesamten Planungsprojektes integrieren. Die *Integration* ist hierbei definiert als die Funktionalität, Daten aus unterschiedlichen operativen Datenbanken miteinander in Verbindung und Einklang zu bringen [11]. Diese Funktionalitäten werden von sogenannten Data Warehouse (DW) Systemen genutzt, um große Datenmengen aus heterogenen Systemen in einer einheitlichen Struktur zu verwalten. Durch die hierbei aufgedeckten Abhängigkeiten zwischen einzelnen „Stellgrößen“ in der

Fabrikplanung können formale, quantitative Zusammenhänge zwischen den Bewertungen der Planungsmodule im Gesamtkontext der Produktionsplanung abgeleitet werden. Dies ermöglicht die Umsetzung wirksamer Intelligence Systeme, die als Unterstützungswerkzeug bei Entscheidungen während des Planungsprozesses fungieren können.

Im Rahmen der vorliegenden Arbeit werden im Kap. 2 zunächst vorhandene Ansätze der Produktionsstrukturplanung sowie einschlägige Intelligence Konzepte vorgestellt. Im Kap. 3 wird der Mehrwert eines integrierten Datenmodells zur Umsetzung einer „Virtual Production Intelligence (VPI)“ beleuchtet. Um eine mögliche Anwendung dieser Plattform in operative Bereiche produzierender Unternehmen zu veranschaulichen, erfolgt darauf basierend die Beschreibung einer Web-Applikation, die als Schnittstelle zur vorgestellten VPI-Plattform fungiert. Schließlich wird im Kap. 4 der Mehrwert einer integrierten Datenplattform für den Fabrikplaner anhand eines Anwendungsfalls aus der Produktionsstrukturplanung aufgezeigt.

## 2 Stand der Technik

### *2.1 Produktionsstrukturplanung in der Fabrikplanung*

Die Layoutplanung bildet einen zentralen Bestandteil der Produktionsplanung. Sie hat sich im Rahmen der funktions- und fertigungsgerechten Zuordnung von Betriebsmitteln zu einem Kernelement der Fabrikplanung entwickelt. Hierbei versteht man unter einer optimalen Anordnung der Betriebsmittel in einer Fabrik in der Regel die materialflussgerechte Zuordnung. Der Materialfluss dient somit als bestimmendes Optimierungskriterium des Fertigungsflusses. Dies liegt vor allem in der hohen wirtschaftlichen Relevanz der Materialflusskosten innerhalb der Produktion begründet [12]. Die Layoutplanung wird einerseits in die Planung des Betriebs- oder Werkstatt-Layouts unterschieden, zum anderen differenziert man zwischen dem Ideal- und Real-Layout [3].

Im Rahmen der vorliegenden Arbeit liegt der Fokus auf dem Ideal-Layout der Anordnung von Produktionsentitäten, genauer auf der Bildung von Prozessketten. Da die anfängliche Segmentierung der Fabrik zu einem großen Anteil durch die Konfiguration der Prozessketten bestimmt wird, kommt diesem Teil der Layoutplanung entscheidende Bedeutung zu. Eine spätere Umstellung von Maschinen ist mit sehr hohen Kosten verbunden, sodass selbst bei ineffizienten Produktionsprozessen in der Regel von einer Rekonfiguration der Produktionssegmente abgesehen wird [12].

Zur Bestimmung einer (materialfluss-)optimalen Betriebsmittelanordnung existieren zahlreiche manuelle und rechnergestützte Verfahren, deren Zielkriterium die Minimierung des Transportaufwandes darstellt [7]. Konventionelle Methoden sowie grafische Verfahren sind prinzipiell durch mathematische und computergestützte Verfahren abgelöst worden. Dennoch sind die traditionellen Methoden immer noch in Fabrikplanungsszenarien vertreten. Eine Evaluation erfolgt zumeist auf Basis spezifischer, für das Projekt hergeleiteter Kennzahlen. Darauf basierend geschieht der

Entwurf eines Punkte-Bewertungssystems, mit dessen Hilfe Alternativ-Layouts des Planungsprojekts in qualitative Relation gestellt werden können [7]. Quantitativ belastbare Evaluationen der entworfenen Fabriklayouts sowie eine Vergleichbarkeit von Prozessketten über die Planungsgrenzen eines einzelnen Projekts hinaus können durch diese Verfahren jedoch nicht realisiert werden. Um dies zu erreichen, müssen mathematischen Optimierungsverfahren bemüht werden, welche in der einschlägigen Literatur in hinreichender Form dokumentiert sind (z. B. [13]).

Neben den sogenannten analytischen Verfahren, die eine exakte Berechnung der Betriebsmittelkonfiguration bezüglich eines Zielkriteriums durchführen, existieren heuristische Verfahren, welche die Layoutplanung auf Basis von algorithmischen, iterativen Optimierungsverfahren unter vertretbarem Aufwand lösen können. Um diesen Prozess der schrittweisen Verbesserung von Planungsverfahren jedoch laufend quantitativ evaluieren und hierauf basierend Entscheidungen bezüglich der Optimierung bereitstellen zu können, bedarf es eines effizienten und durchgängigen Datenmanagements sowie den Einsatz von leistungsfähigen Intelligence-Lösungen.

## *2.2 Intelligence Ansätze in der Produktionsplanung*

IT-gestützte Fabrikplanungssysteme liefern eine Evaluation und Analyse von unterschiedlichen Szenarien der Planung und stellen hierdurch eine Entscheidungsunterstützung bereit. Da die zum jetzigen Zeitpunkt eingesetzten Systeme eine ganzheitliche Abbildung der Planung jedoch nicht leisten, müssen neuartige Konzepte sowohl in Bereichen der Produktionsplanung als auch im Betrieb realisiert werden. Zu diesen Konzepten zählen zum einen sogenannte Intelligence Ansätze, zum anderen die Data Warehouse Systeme.

Ein in den letzten Jahren sehr populär gewordener Begriff im Zusammenhang mit Intelligence-Lösungen ist das Konzept der Business Intelligence (BI), dem die betriebswirtschaftliche Sichtweise von Intelligence-Lösungen zugrunde liegt. Bereits 1958 durch Luhn erstmals geprägt und ab 1993 durch die Gartner Group vorangetrieben (vgl. [14, 15]), beschreibt BI allgemein die Analyse und Nutzung von Unternehmensdaten mithilfe von IT-Systemen zur Entscheidungsunterstützung des Anwenders. Eine eindeutige, allgemeingültige Definition von BI existiert aufgrund der Vielzahl von Protagonisten jedoch bis heute nicht.

So ist es nicht verwunderlich, dass weitere Begriffe wie das operationale BI, Corporate Performance Management, Process Intelligence oder Business Performance Management ähnliche Ansätze beschreiben, die BI weiterführen oder für neue Anwendungsbereiche erschließen. IT-Applikationen, die auf solchen Intelligence-Konzepten beruhen, haben gemeinsam, dass sie Daten innerhalb der unternehmerischen Prozesse *identifizieren*, *aggregieren*, *extrahieren* und *analysieren* [16]. So fallen innerhalb moderner Unternehmen zum einen operative Daten an, zum anderen werden jedoch ebenfalls Anwendungen eingesetzt, die Daten automatisch generieren und sammeln, z. B. unter der Verwendung von Cyber Physical Systems.

Diese Daten können insbesondere in einer vernetzten Infrastruktur im Sinne des Internet of Things bereitgestellt werden. Da die Daten hierbei jedoch meist auf Basis heterogener Systeme generiert werden, bedarf es einer geeigneten Struktur für ihre Aggregation. Die Basistechnologie hierfür stellt das Data Warehousing (DW) dar, das auf Konzepten der multidimensionalen Datenbanken zurückzuführen ist. Ziel dieser Datenbanksysteme ist es, dem Anwender strukturierte Datenverwaltung sowie effizienten Datenzugriff zu ermöglichen [11]. Da unter Verwendung dieser DW- Systeme insbesondere große Datenmengen (*Big Data*) strukturiert aggregiert werden können, stellen sie das Grundgerüst zur Verfügung, um eine effiziente Produktentwicklung auf Basis historischer Daten erfolgreich durchführen zu können. Auf Basis der BI-Systeme im Verbund mit Konzepten des Data Warehousing lassen sich somit leistungsfähige Decision Support Systeme realisieren.

Eine Anwendung von BI-Konzepten auf Bereiche in der Management- und operationalen Ebene erfordert jedoch eine Zusammenführung der unterschiedlichen Werkzeuge. In der Literatur wurden daher Ansätze diskutiert, die eine Verschmelzung verschiedener Intelligence-Systeme bewerkstelligen sollen. In diesem Kontext wird zunächst zwischen den Operational Business Intelligence (OpBI) und den Manufacturing Execution Systems (MES) unterschieden.

Beide Systeme haben gemeinsam, dass sie betriebliche Abläufe analysieren und koordinieren, dies jedoch in unterschiedlichen Segmenten der Wertschöpfungskette. OpBI Systeme stellen mit Hilfe von BI-Technologien wie dem Data Warehousing oder dem Online Analytical Processing (OLAP) Echtzeitinformationen zur Verfügung [17], die jedoch hauptsächlich in Vertrieb und Marketing verwendet werden [18]. Die Manufacturing Execution Systems hingegen liefern IT-Unterstützung innerhalb von Produktionsumgebungen. Dies geschieht vorrangig durch ingenieurwissenschaftlich-orientierte Konzepte, mit deren Hilfe die Abläufe in Produktionsanlagen in Echtzeit organisiert werden können [19].

Eine flexible und an sich ändernde Rahmenbedingungen anpassende Planung kann nur dann realisiert werden, wenn sich die beiden Systeme der OpBI und der MES verschmelzen lassen. Hierbei sollte gewährleistet werden, dass die Daten aus den operativen Quellsystemen in ein zentrales Data Warehouse übertragen und z. B. mit OLAP oder Data Mining Verfahren analysiert werden können [20]. Die Ergebnisse können neben dem strategischen auch im taktischen Management verwendet werden. Eine geeignete Informationsplattform kann vor diesem Hintergrund die Transparenz der operativen Prozesse erhöhen und somit die Leistungsfähigkeit der Prozess- und Produktgestaltung signifikant verbessern.

# 3 Virtual Production Intelligence Plattform

## *3.1 Framework für ein integriertes Informationsmodell*

Die im Kap. 2 erläuterten Konzepte zur Inbetriebnahme und Nutzung von Decision Support Systemen liefert die theoretische Basis für eine zielgerichtete Umsetzung von Produktionsplanungsprozessen unter Verwendung dieser Intelligence-Lösungen. Hierzu bedarf es einer Harmonisierung der Business-Intelligence Ansätze aus der betriebswirtschaftlichen Perspektive eines Unternehmens sowie der derzeitig in der Produktion eingesetzten IT-Systeme. Um die vorgestellten Ansätze also nutzbar zu machen im Sinne eines konkreten Mehrwerts in der Planung, bedarf es eines geeigneten Frameworks zur Umsetzung der konzeptionellen Ideen in ein praktisches Planungswerkzeug.

Die Anforderungen an ein derartiges Framework bestehen zunächst in der überwindung der Heterogenität der vorhandenen Software sowie in der Schaffung von Interoperabilität zwischen den dezidierten Planungssystemen einerseits und zwischen den unterschiedlichen Intelligence-Konzepten andererseits. Aufgrund der stark ausgeprägten Heterogenität vorhandener Software-Systeme lassen sich keine geeigneten Schnittstellen zwischen den Planungsmodulen identifizieren. Eine Kopplung der meist proprietären Software-Systeme lässt sich also nicht ohne weiteres realisieren.

Ein möglicher Lösungsansatz dieser Problematik kann zum Beispiel in der Schaffung eines standardisierten Datenformats bestehen. Wie jedoch frühere Untersuchungen gezeigt haben, ist die Definition eines einheitlichen Datenformats aufgrund des fortgeschrittenen Spezialisierungsgrades der Software-Systeme sowie der hohen Autonomie der Hersteller in der Regel nicht oder nur unter unverhältnismäßig großem Aufwand realisierbar [6]. Ein erfolgreicher Ansatz zur Schaffung von Interoperabilität sowohl zwischen unterschiedlichen Datenformaten als auch zwischen den verschiedenen Planungsmodulen in der Fabrikplanung besteht jedoch in der Schaffung eines gemeinsamen, integrierten Informationsmodells [21].

Eine derartige Datenbasis synchronisiert die bei verschiedenen Simulationen oder Geschäftsprozessen anfallenden Daten auf Basis eines Extract-Transform-Load (ETL) Prozesses und umgeht somit die Problematik der Anpassung von IT-Infrastrukturen sämtlicher Anwendungen. Das dem zugrunde liegende Framework wird als die „Virtual Production Intelligence (VPI)“ bezeichnet, die Datenplattform dementsprechend als VPI-Plattform (z. B. [10]). Dieses Framework ist durch eine entsprechende Konfiguration in der Lage, sämtliche im strategischen, planerischen als auch im taktisch-operativen Bereich anfallende Daten zu sammeln und zu integrieren.

Die Integration erfolgt hierbei in ein zweistufiges Datenbanksystem. Die erste Datenbank bietet eine Art Vorstufe für die zu integrierenden Daten. Hier werden die aus verschiedensten Prozessen anfallenden Daten zunächst in einer vergleichsweise ungeordneten Struktur abgelegt. Auf Basis dieser Daten geschieht nun ein ETL-Prozess, bei dem die Daten zunächst aus der unstrukturierten Datenbank ausgelesen, anschließend im Sinne eines einheitlichen Datenmodells transformiert und schließlich in ein Data Warehouse, eine „intelligente“ Datenbankstruktur, integriert werden.

### 3.2 Web-Applikation als Schnittstelle zur VPI-Plattform

Neben den reinen Funktionalitäten, die die VPI-Plattform zur Verfügung stellt, besteht ein weiterer zentraler Gesichtspunkt in der Schaffung einer geeigneten Benutzerschnittstelle. Dabei wird nicht eine generalisierte übersicht aller durch die Datenbasis eingebetteten Applikationen angestrebt, sondern vielmehr die Aggregation und benutzer- und rollenspezifische Darstellung der Ergebnisdaten, die auf Basis verschiedenster Anwendungen generiert wurden. Diese Schnittstellen eröffnen den an der Produktionsplanung beteiligten Akteuren die Möglichkeit, sich einen umfassenden Gesamtüberblick über alle wichtigen Daten des Planungsprojektes zu verschaffen. Unter Verwendung der Schnittstelle zur Informationsplattform entstehen somit fundierte und quantitativ belastbare Entscheidungen bezüglich des Planungsfortschritts. Unterstützt wird die Planung hierbei zusätzlich durch die zugrundeliegenden Analysemethodiken, die ebenfalls in die Informationsplattform eingebettet sind. Eine Applikation, die diesen Voraussetzungen gerecht wird, muss modular aufgebaut sein sowie über die Fähigkeit verfügen, eine kontinuierliche Verarbeitung eingehender Daten zu bewerkstelligen.

In Vorarbeiten zu vorliegender Publikation wurde eine geeignete eine Web-Plattform entwickelt. Durch Verwendung eines auf dem Google Web Toolkit (GWT) basierten Frameworks ist eine Integration verschiedenster vorgefertigter Widgets in die Web-Applikation möglich. Durch XML-Konfigurationen können somit domänen- und benutzerspezifische Applikationen nach dem Baukastenprinzip aufgebaut werden. Aufgrund der AJAX (Asynchronous JavaScript and XML)-Funktionalität des Frameworks und der damit verbundenen Unterstützung asynchroner Requests lassen sich hierauf basierende Web-Applikationen annähernd intuitiv wie eine Desktop-Applikation bedienen, ohne dabei starke Einbußen bei der Performance zu erleiden.

Der Aufbau und die Funktionalität einer derartigen Web-Applikation lassen sich hierbei sowohl optisch als auch funktional kaum noch von „Offline"-Programmen unterscheiden. Ein weiterer Vorteil der Verwendung einer webbasierten Applikation besteht insbesondere in ihrer Plattformunabhängigkeit. Da die auf dem vorliegenden Framework basierenden Web-Applikationen auf die Ausführbarkeit in jedem modernen Browser ausgerichtet sind, kann die Applikation einerseits auf jedem gängigen Betriebssystem ausgeführt werden, des weiteren sorgt der Einsatz von CSS (Cascading Style Sheets) für ein stets einheitliches Erscheinungsbild der Applikation. Zusammen mit der VPI-Plattform ergibt sich unter Verwendung der Web-Applikation somit ein leistungsfähiges Planungswerkzeug für die Produktions- und Produktplanung. Der Mehrwert einer derartigen Lösung für die Fabrikplanung wird nachfolgend an einem konkreten Anwendungsfall der Produktionsstrukturplanung aufgezeigt.

# 4 Anwendungsfall und Lösungsansätze

## *4.1 Traditionelle Vorgehensweise bei der Layoutplanung*

Der Fabrikplanungsprozess geschieht in den meisten Fällen auf Basis vorhandener Planungsdaten. Dies bedeutet, dass der erste Schritt bei der Konzeption einer neuartigen Produktionsstruktur in der Regel darin besteht, grundlegende Strukturen der Produktion aus vorhandenen Planungsprojekten abzuleiten. Auf Grundlage dieser „historischen Daten" werden dann einige mögliche Produktionskonfigurationen ausgewählt und miteinander verglichen.

Bei der traditionellen Vorgehensweise geschieht dies in der Regel nicht vollkommen auf Basis quantitativer Bewertungskriterien, sondern auch hinsichtlich subjektiver Einschätzungen sowie Erfahrungswerten. Hierbei erfolgt eine Evaluation entweder rein qualitativ oder auf Basis von Punktesystemen, wobei die zu vergebenden „Ratings" auf dem Vergleich mit Planungserfolgen vorangehender Projekte beruhen [12]. Hinsichtlich der Optimierung stellen hier zumeist heuristische Vorgehensweisen das Mittel der Wahl dar. Die Ergebnisse dieser Heuristiken basieren dabei auf Schätzungen, die anschließend mittels semi-analytischer oder iterativer mathematischer Verfahren zu einer „optimalen" Lösung des Problems weiterentwickelt werden. In der Layoutplanung kann das Vorgehen so gestaltet sein, dass zunächst die Anzahl der Segmente bzw. der der Produktionsketten festgelegt wird. Anschließend werden dann entsprechend der Vorgaben Prozessketten gebildet, in denen eine möglichst große Anzahl dieser Produkte abgebildet werden können.

Eine Veranschaulichung der Vorgehensweise bei der Evaluation einer Prozesskette befindet sich in der Abb. 1. Die Kästen repräsentieren die jeweiligen Typen von Produktionsentitäten. Die Pfeile stellen dementsprechend den Materialfluss dar.

Das Beispiel verdeutlicht, dass die in der Mitte dargestellte Prozesskette dazu geeignet ist, sowohl den Bearbeitungsprozess von *Produkt 1* als auch den von *Produkt 2* abzubilden. Die mit der Prozesskette übereinstimmenden Sequenzen in der Wertschöpfungskette der jeweiligen Produkte sind hierbei durch die angedeuteten Rahmen veranschaulicht. Das Ziel einer optimalen Konfiguration der Produktion besteht darin, die Prozessketten so zu gestalten, dass eine möglichst große Anzahl der zu fertigenden Produkte ohne logistischen Mehraufwand innerhalb dieser Prozessketten abgebildet werden können. Die Formulierung „ohne logistischen Mehraufwand" bedeutet hierbei, dass kein Produktionsschritt der Prozesskette übersprungen oder doppelt ausgeführt werden darf. Dies ist bei beiden in der Abb. 1 dargestellten Produkten der Fall.

In der Praxis von Produktionsplanungsprozessen werden häufig Prozessketten abgeschätzt, diese anschließend mit den zu fertigenden Produkten abgeglichen und anhand sogenannter „Probierverfahren" weiter optimiert. Diese Verfahren beruhen auf dem erwähnten Expertenwissen und entbehren daher einer quantitativen Grundlage. Neben diesen Probierverfahren werden heuristische Verfahren angewandt, um die Produktionsstruktur zu optimieren. Die Problematik besteht hierbei in der Einbettung von Planungsergebnissen in ein Gesamtmodell aller Planungsmodule

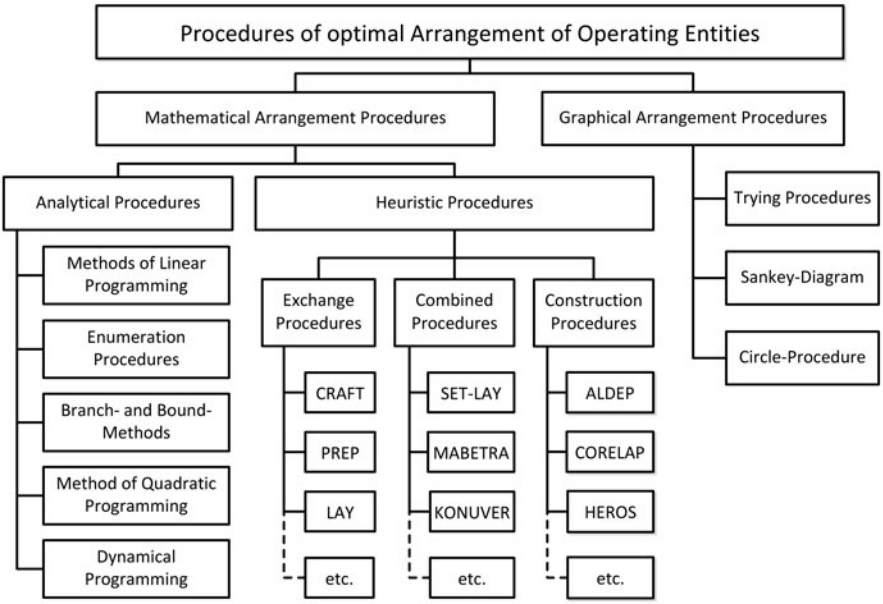


**Abb. 1** Abbildung von zu fertigenden Produkten auf einer Prozesskette

der Produktionsplanung. Eine Evaluation jeder Prozesskettenkonfiguration ist daher in der Regel mit einem hohen bis nicht vertretbaren Aufwand verbunden, da die Ergebnisse vorangegangener Planungsmodule meist manuell in weiterführende Evaluationswerkzeuge eingepflegt werden müssen.

## *4.2 Prozesskettenoptimierung unter Verwendung eines iterativen Algorithmus*

Im Folgenden wird gezeigt, dass die Planung unter Verwendung von Intelligence Werkzeugen, hier insbesondere der VPI-Plattform, sowohl bei heuristischen als auch bei analytischen Verfahren signifikante Vorteile gegenüber einer dezidierten Herangehensweise an die Optimierung hat. Im Rahmen der vorliegenden Arbeit wurde daher ein iterativer Algorithmus entwickelt, der auf Basis historischer Produktionsdaten eine optimierte Bestimmung von Prozessketten vornimmt.

Die Produktionsdaten werden hierbei durch eine Produktliste repräsentiert, die neben der Art der Produkte außerdem detaillierte Informationen zu den Fertigungsstufen bereitstellt, die das jeweilige Produkt bis zu seiner Fertigstellung durchlaufen muss. Hier soll zunächst nur der reine Algorithmus beschrieben werden, seine Einordnung in den Gesamtkontext sowie in die Funktionalität der Intelligence Unterstützungssysteme werden im darauffolgenden Abschnitt erläutert. Der Algorithmus führt auf Basis historischer Produktionsdaten ein Optimierungsverfahren durch. Daher werden aus den vorhandenen Produktdaten zunächst Prozessketten gebildet. Anschließend werden innerhalb dieser Prozessketten übereinstimmungen sowie Regelmäßigkeiten identifiziert. Dies geschieht durch quantitative Maße, die auf Grundlage von Zählverfahren implementiert wurden. Auf Basis dieser Zählverfahren wird eine A-Priori-Abschätzung sinnvoller Prozessketten durchgeführt.

Diese vorläufigen *Hauptprozessketten* werden mit Hilfe statistischer und heuristischer Verfahren evaluiert und unter Verwendung eines iterativen Optimierungsalgorithmus so lange modifiziert, bis eine bestimmte Abdeckung der zu fertigenden Produkte durch die *Hauptprozessketten* gewährleistet ist. Während des Algorithmus wird überprüft, welche Prozessketten und dementsprechende Produkte sich auf den *Hauptprozessketten*, nachfolgend als *MainChains* bezeichnet, abbilden lassen. Diese werden in der Programmlogik folglich mit dem Attribut *RegularChains* belegt. Neben diesen werden bei dem Verfahren weiterhin die Prozessketten ermittelt, deren passende Produkte sich *nicht* auf den *MainChains* abbilden lassen. Diese Ketten werden als *SpecialChains* deklariert.

Während der Durchführung werden bei jedem Schleifendurchlauf zunächst die aktuellen *MainChains* evaluiert. Anschließend werden im Rahmen eines Vertauschungsverfahrens die *MainChains* wiederum teilweise durch Prozessketten ersetzt, die auf Basis einer quantitativen Analyse der *SpecialChains* ermittelt wurden. Dieser Prozess wird so oft wiederholt, bis ein bestimmtes quantitatives Maß der Produktabdeckung durch die *MainChains* erreicht wird.

## 4.3 Die Layoutplanung als ETL-Prozess mit dem Ziel einer dynamischen Optimierung

Der im vorherigen Abschnitt vorgestellte Algorithmus liefert einen wichtigen Beitrag zur Durchführung eines Produktionsplanungsprojekts. Diese statische Optimierung des Fabriklayouts kann jedoch nicht losgelöst von anderen Modulen der Planung betrachtet, sondern muss in den Gesamtzusammenhang eingeordnet werden, um vollständig evaluiert werden zu können. Während dieser Evaluation muss in der Regel eine Vielzahl von Parametervariationen in jedem der Planungsmodule vorgenommen werden, um zu einer optimalen Lösung des Gesamtproblems zu gelangen. Der Vorteil in der Verwendung eines Intelligence Systems, speziell der Virtual Production Intelligence, liegt darin, dass die Optimierungsalgorithmen für einen vollständigen Parameterkorridor durchgeführt und die Ergebnisse hierbei so abgelegt werden können, dass diese im Rahmen der konkreten Optimierung des Gesamtproblems direkt und ohne weitere Aufwände aufgegriffen werden können.

Diese Vorgehensweise sei am Beispiel des oben beschriebenen Algorithmus demonstriert (siehe Abb. 2). Der Algorithmus der Prozesskettenbestimmung wurde hier in einen bei Intelligence und Data Warehousing Konzepten gängigen *Extract-Load-Transform (ETL)* Prozess integriert. Zu Beginn dieses Prozesses werden vorhandene Produktionsdaten aus der Datenbasis abgerufen und zur Generierung

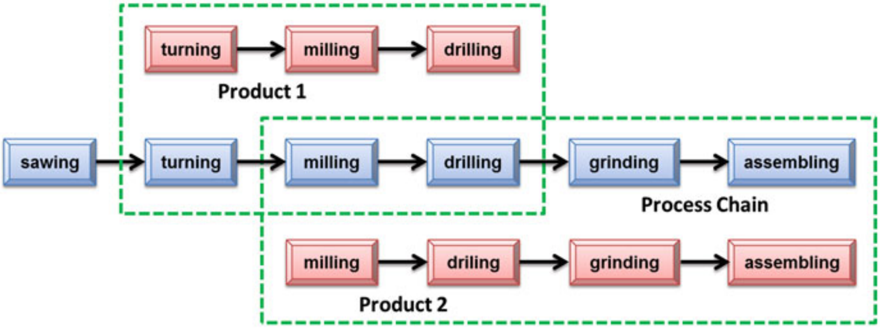


**Abb. 2** ETL-Prozess der Layoutoptimierung in der Fabrikplanung

von Prozessketten verwendet *(Load)*. Anschließend kommt der Algorithmus im *Transform*-Prozess zum Einsatz.

Ein Parameter, der während der Optimierung des Fabriklayouts variiert werden kann, stellt die Anzahl der Hauptprozessketten *(MainChains)* dar. So kann die Optimierung zum Beispiel für eine Anzahl von 3–5 *MainChains* durchgeführt und evaluiert werden. Der Benutzer kann daher zu Beginn der Berechnung, z. B. auf Basis architektonischer Vorgaben festlegen, wie groß die Anzahl der *MainChains* minimal (*numMainChains* [= 3]) und wie groß diese maximal sein darf (*maxMainChains* [= 5]). Darauf basierend wird der oben beschriebene Algorithmus mehrmals durchgeführt. Die Ergebnisse der einzelnen Durchläufe werden in einer multidimensionalen Datenbank so abgelegt, dass die Ergebnisse jedes durchgeführten „Planungsszenarios“ modular abgerufen werden können.

Neben der in Abb. 2 beispielhaft dargestellten Parametervariation „Anzahl der Hauptprozessketten“ können Variationen auch für andere Parameter durchgeführt werden. Bei der späteren Planung stehen die Ergebnisse der verschiedenen Algorithmen dann für den gesamten relevanten Parameterkorridor zur Verfügung. Hierdurch ergibt sich ein signifikanter Mehrwert in der Planung, da Modifikationen so in beliebiger Reihenfolge und Häufigkeit durchgeführt werden können.

Der Benutzer, der die vorgestellte Web-Applikation für den Planungsprozess verwendet, benötigt hierbei keinerlei Kenntnis von den eingesetzten Algorithmen. Da sowohl die Produktionsdaten als auch die Ergebnisse sowie Evaluationen mit Hilfe der VPI-Plattform verarbeitet wurden, erhält der Benutzer nur die auf seine Parameterauswahl zugeschnittenen Ergebnisse. Durch das Data Warehouse System wird hierbei gewährleistet, dass die angezeigten Lösungen in den Gesamtkomplex des Produktionsplanungsvorhabens eingebunden werden. In der Folge werden die Ergebnisse entsprechend der gewählten Parameter automatisiert anhand ihrer Abhängigkeiten zu den anderen Modulen des Planungsprojektes in eine Gesamtevaluation der Planung einbezogen.

## 5 Zusammenfassung und Ausblick

Anhand eines Anwendungsfalls aus der Produktionsstrukturplanung konnte gezeigt werden, dass sich durch den Einsatz von Intelligence Systemen, insbesondere der Virtual Production Intelligence, ein signifikanter Nutzen bei der Modellierung von Produktentwicklungsprozessen unter Berücksichtigung verschiedenster Randbedingungen und Abhängigkeiten erzielen lässt. Die VPI-Plattform ermöglicht zudem eine integrative, ganzheitliche Sicht auf verschiedene Szenarien der Produktplanung. Die Ergebnisse der einzelnen Planungsmodule für verschiedene Parameter und Produktkonfigurationen können somit im Gesamtkontext der Produktionsstrukturplanung evaluiert werden. Es lassen sich somit fundierte Prognosen über den Planungserfolg zu jedem Zeitpunkt der Planung erstellen.

Im Rahmen der optimierten Produktions- und Produktentwicklung bestehen die nächsten Schritte darin, die vorgestellten Konzepte sowohl hinsichtlich algorithmischer als auch methodischer Gesichtspunkte weiterzuentwickeln. Daher werden zunächst weitere Algorithmen und Kennzahlen für die Berücksichtigung zeitlicher Aspekte in der Produktion implementiert. So soll zum Beispiel der Prozesskettenbegriff hinsichtlich seiner Dimension erweitert werden. Die hieraus resultierenden mehrdimensionalen Prozessketten sollen zeitliche Abhängigkeiten zwischen den Bearbeitungsschritten in der Produktion berücksichtigen. So kann zum Beispiel der Prozesstakt durch Parallelschaltung von Produktionsentitäten mit dem Ziel einer Minimierung von Wartezeiten optimiert werden.

Hinsichtlich der methodischen Weiterentwicklung sollen die vorgestellten Konzepte der Integration und Verwaltung von Daten auf die verschiedenen organisatorischen Bereiche produzierender Unternehmen erweitert werden. Ein Datenaustausch soll hierbei nicht nur zwischen den ERP-Systemen des Managements und der taktischen bzw. planerischen Ebene, sondern insbesondere auch zwischen der operationalen und den darüber liegenden Ebenen stattfinden.

Die sich hieraus ergebenden Herausforderungen an die Integration und Datenhaltung werden durch eine Erweiterung der Virtual Production Intelligence und Data Warehouse Konzepte angegangen. Hierbei sollen die Daten aus der operationalen Ebene (Cyber Physical Systems) so aufbereitet werden, dass sie sowohl in die Manufacturing Execution Systems als auch in die ERP-Systeme nutzenbringend integriert werden können. Erst durch die Realisation der Operabilität zwischen diesen Bereichen lässt sich eine vollständige virtuelle Abbildung des Produktionsprozesses erreichen. Auf Basis der ganzheitlichen Vernetzung lassen sich Werkzeuge zur aktiven Entscheidungsunterstützung realisieren, die durch Daten aus der gesamten Produktion eine stetige Verbesserung der Produktions- und Produktentwicklung gewährleisten.

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# Multi-Dimensional Production Planning Using a Vertical Data Integration Approach

## A Contribution to Modular Factory Design

**Max Hoffmann, Tobias Meisen, Daniel Schilberg and Sabina Jeschke**

**Abstract** Due to the continuously and fast increasing complexity of products and production processes, manufacturing companies have to face more and more challenges in order to survive on a competitive market. Thus, in modern planning scenarios of the manufacturing process, the goal is not only to achieve the most efficient low-cost production, but also to take into account the interests of the customer. Especially the increasing impact of the customer on the market leads to rapidly changing boundary conditions and thus different requirements concerning the production process. As a consequence, the production has to be designed more flexible and adaptive to changing circumstances. In order to reach the desired flexibility, the production as well as the communication management within the factory has to be designed on the basis of a modular planning approach. This requires vertical exchange of information through all levels of the company, from the management layers and the Enterprise Resource Planning (ERP) to the automation and shop floor layers, where the aggregated information is needed to optimize the production. The interconnection of these corporate layers can only be achieved through the use of an information model that serves interoperability between these mostly heterogeneous systems. The processing and visualization of ERP data using an integrative information model enables a continuous optimization of the production systematics. Through the information model, cross-linked data structures of the production monitoring and automation can be connected and thus be integrated and consolidated into a consistent data basis. In the current work, such an information model will be introduced and validated by making use of an optimization algorithm that is carried out through the layout planning phase of a factory. The use-case scenario presented aims for serving a flexible and dynamic optimization of the production structure of a manufacturing enterprise. During the optimization, the algorithm takes into account historical data taken from the ERP level of the company as well as time constraints to design multi-dimensional process chains for multiple manufacturing scenarios.

**Keywords** Data Mining · Big Data · Virtual Production Intelligence · Operations Research · Operations Management · Factory Planning

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# 1 Introduction

In the context of modern factory planning scenarios, some key competencies are of primary importance. Hereby, we are concentrating on leading positions in cost minimization, quality management and the individual care for consumer interests [1]. The education and the application of those key competencies during the planning of a factory make a decisive contribution to the "competitive strategy" of modern companies [2]. This strategy constitutes how the different players of the market will determine their strategic product-market-combinations in order to reach a competitive advantage against their concurrence [2].

In connection with rapidly rising challenges due to the globalization of the markets, the manufacturer's impact on the market decreases. However, the expectations and requirements defined by the consumers concerning the quality and flexibility of the products increases. This leads to a higher dominance of the customer on the market [3] and causes higher expectations concerning the design and the variety of the products as well. As a consequence, the customer expects products to be as cheap as mass products, but also as flexible and modular as being produced in low volume production. This requires novel concepts in production design and planning, because products need to become more complex and flexible, whereas the technology dynamics increase and innovation cycles shorten.

However, current manufacturing environments, especially within highly automated industrial segments, are still focused on mass production [4]. This creates high planning certainties as well as an efficient production and high working cycles. At the same time, individual products are not easily realizable.

Due to the rising interests of consumers in an increasing variety of the products, the modularity of the production gains in importance. Thus, necessary modifications of the production structure and their impact to technical and economic aspects have to be taken into consideration already during the planning process. As the consideration of all such dependencies in the factory and production structure planning process is highly complex and often imponderable, the planning has to be divided into distinctive planning steps, thus a modular planning procedure is needed. One approach to the modularization of the planning was introduced by Schuh et al. [5]. The presented "Condition Based Factory Planning" approach splits the factory planning into distinctive planning steps in order to create a more structured and systematic way of dealing with multiple degrees of freedom in production planning. The advantages of such a planning approach consist of the determined procedure of factory planning projects and the possibility to split the process into working packages, which can be performed by the according experts. The next step of this approach consists in the consideration of interdependencies between the different planning modules. The establishment of interconnections between these modules is hereby complicated due to the use of different optimization methodologies and tools in the different planning domains. The structure and embedding of different planning modules is depicted in Fig. 1.

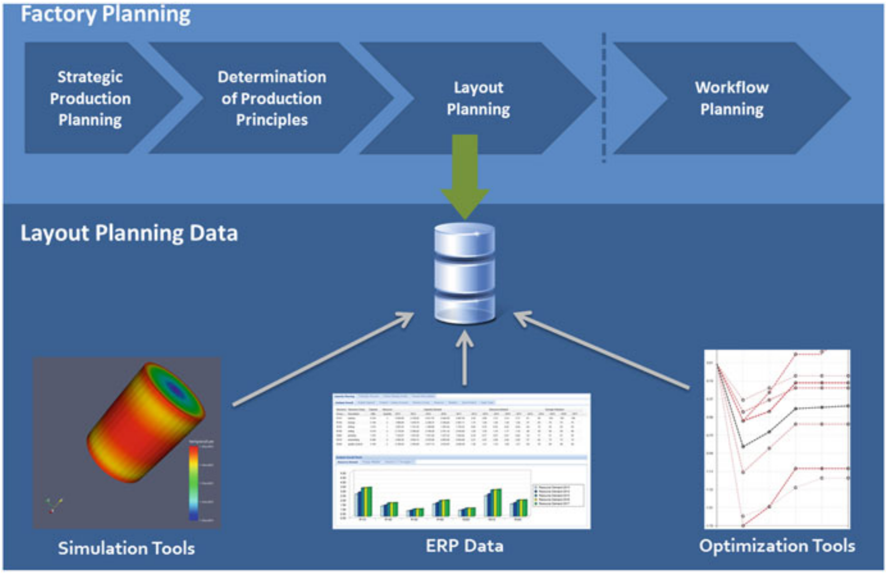


**Fig. 1** The layout planning of a modular factory planning approach

The top of the picture shows a section of the factory planning working chain. It consists of the planning modules described earlier. Within the current work, especially the layout planning module is examined. With regard to the layout planning, different relevant sources of data can be identified as shown in the lower area of Fig. 1. Besides the information from the ERP level, data taken from already existing production sites, which are referred to as "historical data", as well as data taken from simulation and optimization tools are used to perform the layout planning. In order to combine these different information into one holistic view, an embedded platform has to be carried out that is capable of managing all information provided. Such shared IT-environment requires an integrative information model as well as a common data basis that supports communicative and administrative support of concurrent simultaneous engineering processes [6].

In order to reach a consistent factory design as described above, the different planning modules have to be linked in terms of such holistic model. Hence, a common information management system is needed, which is capable of integrating the different planning modules into one integrative information model. Thus, the goal of a holistic factory planning consists in the definition of an information model that contains not only the capabilities to integrate the different modules of the factory planning process, but also to manage the information generated and provided by various sources. In order to practically use an information platform that is capable of these functionalities, a software framework will be utilized to integrate the layout planning module into the overall factory planning context. The framework in use, which is referred to as "Adaptive Data Integration using Services (ADIUS)", is based on the concept of “Virtual Production Intelligence (VPI)” and serves as an information platform and thus enables operations beyond all planning modules and tools concerning factory planning.

In the present work, the state of the art in layout planning and data integration with the focus on vertical data exchange will be examined in Sect. 2. In order to reach an adaptive optimization approach, the planning process of a factory needs to be structured in a more flexible way. Thus, a layout planning approach, which takes into account multiple scenarios, will be described in Sect. 3. Accordingly, in Sect. 4, the added value of such an approach is demonstrated by making use of a complex planning problem, before first practical results will be demonstrated in Sect. 5. In the use-case, the traditional layout planning process will be extended by taking into account time constraints by applying a flexible planning algorithm.

## 2 State of the Art

### *2.1 Layout Planning*

Layout planning represents a central part of the factory planning and has advanced to a core element of production planning in the context of functional and production-oriented allocation of resources. The optimal allocation of resources can be understood as the material flow-fair assignment. Thus, the flow of material serves as a defining criterion for the optimization of the production flow. This is mainly due to the high economic relevance of the material flow costs compared to the overall costs of the operating factory [7].

Layout planning of a factory is carried out in several steps and is based on planning modules. According to the VDI [8], layout planning is part of the conceptual planning of a factory and is carried out by determining the ideal layout first and the real layout afterwards. The derivation of the ideal layout is hereby comprised of structure planning and the dimensioning of resources. Afterwards, the production control, the logistics and the information and communication flow are determined in terms of the real factory layout. The relevant literature shows a wide range of approaches to layout planning [7, 9].

According to the current state of the art, the ideal layout is initially designed using existing production data before it is adapted to other requirements of the production facilities. Thus, the first step in designing a production structure is to derive basic structures of the production from existing factories or planning projects. Existing data or manufacturing information can for instance consist of product lists, processes, quantities and other variables of the Enterprise Resource Planning. Based upon these “historical data”, several possible scenarios of the production configuration are selected and compared.

The planning of the ideal layout is hereby independent of the variables associated with the design constraints of the real layout planning, which takes into account all relevant boundary conditions, e. g. architectural or legal restrictions. Thus, the ideal layout planning determines the production configuration only in terms of an optimized material flow. Numerous analytical, heuristic and graphical methods have been carried out in order to support a structured determination of the ideal layout [10]. The considerations of all boundary conditions happens in later steps of the planning through the application of further planning modules in order to determine the real layout of the plant [7]. A well-structured summary of the different approaches and factors influencing the layout planning process is provided by Kampker et al. [11].

Nevertheless, especially the step from the ideal to the real layout is usually influenced by the knowledge of experts and is therefore principally shaped through experience values. Accordingly, the main challenge in layout planning is the quantitative measurability of various scenarios with the aim to determine an optimal solution – not at least due to the fact that the approaches to determine the real layout are only documented in a qualitative and abstract form. Hence, there is a lack of explicit instructions in the literature regarding the compliance of conditions such as ensuring the flow of communication as well as the flexibility and modularity of the production. Similarly, there are only few quantitative approaches for estimating the costs arising from the consideration of all according boundary conditions [11].

At present, an individual evaluation system has to be developed for each production planning project. This system is not only based on the conditions of the current project, it also takes into consideration historical planning data. On the basis of this rating system, different scenarios are evaluated and compared with each other in order to determine the "optimal" factory layout. The evaluation is either based on qualitative or on semi-quantitative methods using point evaluation systems, whereas the "ratings" are based on the comparison with planning successes of previous projects. The disadvantages of this approach are the low reproducibility of planning successes as well as the low degree of systematization of the planning process. Due to the uncertainties, which are accompanied using this way of optimizing the layout of the factory, the results have to be adaptable and flexible for later modifications. In order to evaluate the planning success in each later step of the factory planning and from each level of the manufacturing enterprise, a holistic and pervasive vertical data integration needs to be established within the planning processes.

## *2.2 Vertical Data Integration*

One of the most important approaches concerning the cross-linking of different scopes in enterprises has arisen from the Business Intelligence (BI) movement [12]. Initially, BI was introduced to interconnect the different departments of a company from the economic point of view [13]. However, due to their data-oriented, enterprise-wide character, BI can also serve interconnection functionalities as well as decision support within a connected environment of production facilities. The basic idea of Business Intelligence is to collect and to process information in order to gain a deeper understanding of processes in companies. These intelligence functionalities can be applied either on the economical part of an organization or within the production environment of the company.

In terms of production planning, intelligence tools can be used for both analyzing historical manufacturing data as well as processing real-time data taken from the production process. An establishment of cross-sectional data treatment processes in the production environment is necessary to guarantee a propagation of information to all people who are involved in planning processes in an appropriate form [13].

With regard to the factory planning domain, intelligence tools like BI can support the integration of different tools into one optimization framework through a consistent information model. In this context, numerous software solutions exist providing an IT support in the planning phase. However, most of the existing systems are stand-alone solutions that focus on one aspect of the planning task and are therefore insufficient with regard to the evaluation of the overall planning process. These tools do not build a monolithic system, so that a homogeneous connection of the IT environment will probably not be possible [6]. In order to apply the BI idea on the different tools of a manufacturing enterprise, the BI term has to be extended on different fields on the management and on the production level at the same time.

In order to spread this Business Intelligence approach to the field of production, other terms have been introduced such as the operational Business Intelligence (OpBI), Corporate Performance Management (CPM), Process Intelligence or Business Performance Management, which continue the idea of BI on new fields of application [14]. Accordingly, approaches have been discussed in the current literature that could lead to a merge of intelligence systems from the different levels of a manufacturing enterprise. In this context, a first differentiation is made especially between Operational Business Intelligence (OpBI) and Manufacturing Execution Systems (MES).

Both concepts have in common that they analyze and coordinate entrepreneurial processes. However, they operate in different sections of the value chain. OpBI systems provide real-time data analysis through BI technologies like Real-Time Data Warehousing and Online Analytical Processing (OLAP), but they are focusing on data models and on functions of sales and marketing [15]. MES, however, provide data consolidation and monitoring capabilities within the production environment. This is primarily performed through engineering-oriented concepts, which are capable of organizing the manufacturing processes [16]. A flexible planning, which is able to manage changing and unexpected circumstances within production can only be realized through the interoperability of OpBI and MES. Hereby, the data collection and analysis from different levels of the company has to be guaranteed as well as the integration of the according information into a database system [17].

An integrative solution to serve the desired interoperability between these heterogeneous, distributed systems was shown with the adaptive information integration according to Meisen et al. [18]. A framework based on this approach allows the creation of an integrative information model in connection with the propagation of data into a common data basis, which contains both input and output data from various applications in a structured form [19]. This framework and the according information model enable an establishment of Business Intelligence approaches into the domain of virtual production and are referred to as "Virtual Production Intelligence (VPI)".

## 3 Vertical Data Integration Using the Virtual Production Intelligence Platform

The Virtual Production Intelligence allows a merge of heterogeneous planning, simulation and optimization tools. Based on the information model, a platform has been carried out that is capable of integrating information from different corporate processes, production processes and simulations into one common data basis [19]. This multi-dimensional data basis enables – through the integrative methodology of the common information model – a vertical data flow of information from all levels of the production management and operations.

This vertical information flow is necessary to enable a full mapping of the processes in a manufacturing company. In order to guarantee a holistic optimization of production processes, the flow of information has to be designed especially for simultaneous data propagation and data treatment. These functionalities are only realizable through methodologies, which enable an integration of data from different sources into central data storages. These data can, for instance, consist of data taken from the ERP level or of sensor values taken from the field levels. The merge and the common analysis of these data sets are essential for a sound and well-founded analysis of the processes that can be understood by the experts involved in the planning of the production. The needed interface for the interaction between the user and this system can be realized through database views that are based on the described information model. Thus, through a full integration of all relevant information, the optimization system is capable of providing all needed information to the user by visualizing the data within diagrams or by showing reports of aggregated data sets. According to Vogel-Heuser [20], the goal of connecting the production systems with a distributed IT environment can be reached by integrating an information layer between the production site and the IT systems (Fig. 2). This intermediate layer replaces the interfaces between applications from the manufacturing layer and the information management layers.

Through the information model's capability to interpret data from the field level of the production, single connections between the machinery and hardware (bottom in Fig. 2) and the IT environment (top in Fig. 2) are obsolete.

In order to enable the interpretation of data, the information model has to contain semantic knowledge about the production process as well as the different actuators, sensors and IT systems used within production. Using this information in connection with domain-specific knowledge, the information model is able to transform the information in order to enable a consolidation of the information in the data structures of the IT environment within the enterprise administration level.

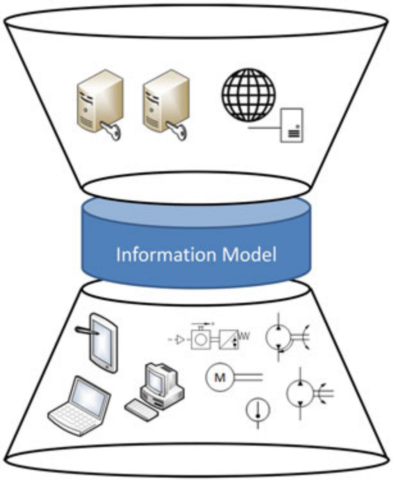


**Fig. 2** The Information Model Layer for a connected IT environment

The idea of inserting a semantic information model as an intermediate layer can also be utilized in the interconnection of significantly heterogeneous software systems or planning tools. Hence, the information model, which was introduced together with the VPI platform, is capable of serving an intermediate information layer between distributed applications and simulation or optimization tools. By using the domain-specific knowledge about different optimization and software tools, the VPI integrates multiple planning and optimization steps into one holistic planning model. As a consequence, modifications in single planning steps will have an impact on the overall planning results, because changes in the project configuration are immediately integrated into the overall planning context.

In the next section, the advantages of integrating a formerly distinctive optimization tool into the overall idea of the factory planning project is demonstrated by means of a layout planning use-case. Through the integration of different results for determined process chains into an integrative data basis, modifications and parameter variations can be dynamically performed at any stage of the planning progress.

## 4 Multi-Dimensional and Multi-Variant Process Chain Optimization in Layout Planning

As mentioned in the state of the art section, layout planning is intrinsically characterized by the knowledge as well as by the experience values of experts. Hence, decisions made during the planning and determined results are commonly not evaluable in an entirely quantitative way. As a consequence, modifications and corrections during the planning are inevitable. In order to integrate these changes into further

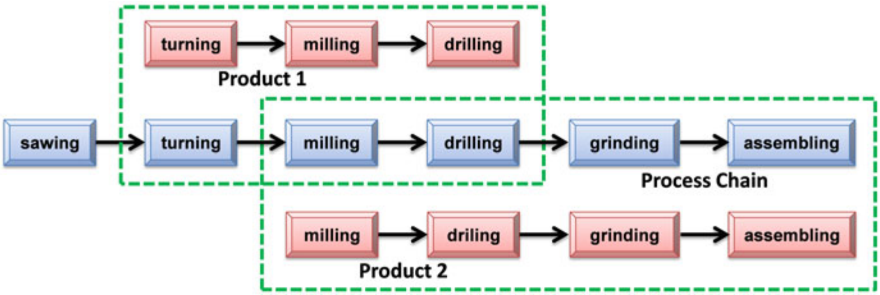


**Fig. 3** A Process Chain designed by the manufacturing steps of products

factory planning steps, an information model can serve features to identify cross-module connections within the planning to integrate the according changes in all affected planning modules.

In order to store the information as well as domain-specific knowledge about the identified cross-module references into a database by making use of a suitable information model, multi-dimensional databases are one well-established solution. For instance, so-called Data Warehouses are filled by performing Extraction-Transform-Load (ETL) processes. In the extraction phase, comparatively sparsely structured data is extracted from a common relational database. In the transformation step, these data are treated to take into account different information views and to facilitate reporting functionalities. In the last step, the data is loaded into a Data Warehouse.

The layout planning use-case that is carried out in order to demonstrate the advantages of applying multi-dimensional databases in the planning is initiated by data taken from the ERP level of a producing enterprise. The according data sets provide basic information about the manufacturing process of products, for example resource group numbers, machinery usage, production segment assignment as well as dates and manufacturing durations. The resource group number, which represents the machine in use, is of special interest here, because it can be used to carry out a formal description for the manufacturing process of each product. Thus, the production process of each single product can be expressed by process chains, a row of determined manufacturing steps (Fig. 3).

The goal of the layout planning primarily consists in the determination of the most common process chains. If the manufacturing entities within a factory are placed according to this optimal configuration, the respective products will be manufactured using a minimum of logistical efforts. The optimization process to perform this ideal allocation of manufacturing resources is carried out in several steps:

1. Identification of repetitive process chain patterns,
2. Determination of an a-priori solution for the optimized process chain configuration,
3. Validation and improvement of these process chains by an iterative optimization algorithm,

4. Application of time constraints in order to perform a multi-dimensional machinery allocation optimization.

At first, the given product list, which consists of more than 30k products, is quantitatively analyzed in order to determine the most frequent products of the historical ERP data. This step is performed using counting methods and similarity patterns within the process chains. Due to the huge amount of possible solutions for this logistical optimization, the determination of the optimal solution is connected to an NP-hard problem.

Consequently, the described quantitative methods can only lead to a semi-optimal solution. This solution is then defined as the a-priori solution to the problem and further developed using iterative optimization steps. This iterative approach is carried out by the following procedure. Firstly, preliminary determined chains are checked concerning redundancies and similarities that could be caused by a high dominance of repeating products. In the next steps, these overlapping process chains are systematically replaced by process chains, which represent product configurations that have been undermined within the first optimization step, but are also of primary importance.

In the following step of the process chain formation, time constraints are applied to dynamically further optimize the identified process chains. During the dynamical optimization phase, the previously one-dimensional process chain term is enhanced to multi-dimensional chains in order to be capable of taking into account different manufacturing times of various machines within the production process. Hence, this multi-dimensional approach allows a parallel arrangement of the production entities within one manufacturing chain. As a consequence, waiting times of rather quick or slow machines can be rearranged in order to reach a continuous flow of the products, which have to be manufactured.

The algorithm (point 4) that provides these functionalities is comprised of several steps that are performed as follows:

4a. Determination of the maximum number of parallel machines for each process chain due to general considerations like space requirements et cetera:

$$n_i = n_{i,max} \tag{1}$$

4b. Identification of the machine $i$ within each process chain that has got the maximal manufacturing time $t_i$,

$$t_i = t_{i,max}(n_i) \tag{2}$$

4c. Calculation of the ideal number for each other process chain machine $j$ by using the process times $t_i$ and $t_j$,

$$\forall n_j, j \neq i : n_j = n_i \cdot \frac{t_j}{t_i} \tag{3}$$

4d. Logical determination of the real number for each machine considering the maximal number of parallel machines and the ideal number for each machine if

$$\left|\frac{t_j}{n_j} - \frac{t_{j-1}}{n_{j-1}}\right| > \left|\frac{t_j}{n_{j+1}} - \frac{t_{j+1}}{n_{j+1}}\right| \tag{4}$$

then

$$n_j := n_j + 1 \tag{5}$$

This last step of the algorithm is performed in order to assess the buffer time of slow machines that are fully occupied to the waiting times of faster machines that are not working on its capacity limit. Hence, this optimization procedure creates a setup of process chains with multiple degrees of freedom and thus compromises between inevitable waiting and buffer times.

## 5 Preliminary Results

In preliminary test scenarios, the full algorithm as described was performed multiple times for several parameter variations. The hereby determined process chains were continuously validated by matching the manufacturing configurations of the products from the ERP systems. After several iterative steps, the results were approaching to a certain boundary value that cannot be further improved using static optimization methods.

For this specific test case, the parameter variation was performed for the total number of machine chains in a factory, thus the range of this particular parameter was varied between e. g. 3 and 6. Hence, each run of the algorithm determines a fixed number of so-called main process chains, which represent the ideal machine configuration for this specific use-case.

The results of each run were then integrated through the integrative information model served by the VPI Platform. Thus, the different parameter configurations can be selected modularly for different use-cases or optimization scenarios. The results of each optimization run can consequently be visualized continuously within a Web application, which was developed for information management purposes. The use of the web interface allows a user defined parameterization of the different scenarios as shown in Fig. 4.

In the figure a screenshot of the user interface for the layout planning module of the factory planning application is shown. The results for the process chain optimization algorithm that are visualized in the UI can be modified at each step of the planning progress. The dependencies of these variations to other planning modules are consequently integrated in the overall planning process. The results for each specific parameter configuration can thus be utilized in all following planning steps without further efforts.

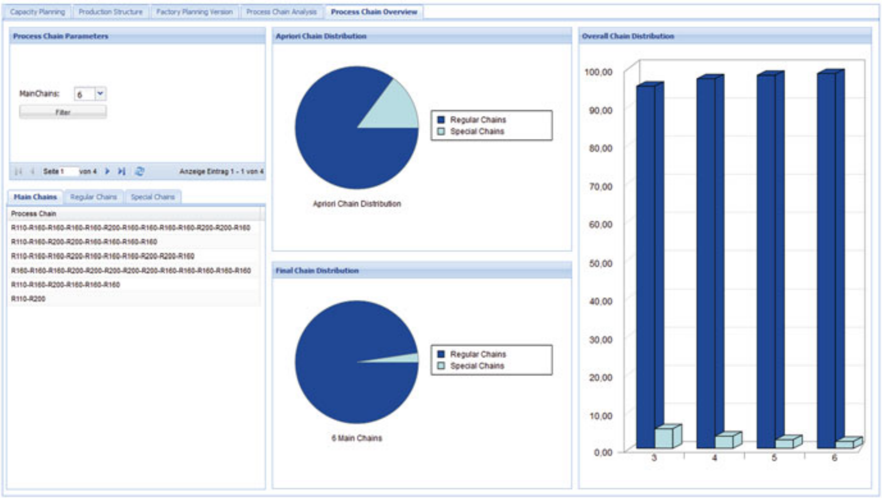


**Fig. 4** Web-App forths parametrized visualization of optimization results

## 6 Conclusion and Outlook

Based on a use case it was demonstrated that the use the Virtual Production Intelligence result in far reaching benefits in production planning. Due to the application of the VPI platform various constraints and parameters can be considered in the planning. This enables an integrated, holistic view of various scenarios of the factory planning so that individual modules of the production planning can be evaluated in the overall context of the planning process. Quantitatively reliable statements over the planning success can thus be made at any time.

In the context of optimized production planning, the next steps will consist especially in expanding the concepts presented in terms of a holistic interconnection of all levels involved in the production planning as well as in the manufacturing process.

On the methodological side, the presented concepts of the vertical integration of production data have to be realized by extending the Virtual Production Intelligence Platform in terms of data flows from MES and the field level. These information need to be processed and aggregated automatically so that they are available within the ERP systems and production planning. Only through the interoperability between these systems an integrated digital mapping of the production is possible. This provides the basis for intelligent tools for the planning and decision support in order to ensure a continuous improvement and further development of the production planning process.

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# Optimized Factory Planning and Process Chain Formation Using Virtual Production Intelligence

**Max Hoffmann, Kai Kreisköther, Christian Büscher, Tobias Meisen, Achim Kampker, Daniel Schilberg and Sabina Jeschke**

**Abstract** The increasing complexity of products creates new challenges in production planning. Hence, the methodology of process development has to be designed valuable. An innovative approach to reach efficient planning consists in the virtualization of planning processes. The concept of the "Digital Factory" enables a preliminary evaluation of the planning success. In the present work, a framework is presented, which allows for the integration of dedicated applications into an integrative data model to gain a holistic mapping of the production. Using Intelligence approaches, data can be analyzed to provide decision support and optimization potentials. The advantages involved are demonstrated by a production structure planning approach in connection with a process chain optimization.

**Keywords** Digital Factory · Virtual Production · Business Intelligence · Virtual Production Intelligence · Cyber Physical Systems

## 1 Introduction

In order to stay competitive within an economic environment, which is characterized by globalization and networking, so-called key competencies are indispensable in the process of modern factory planning scenarios. These competencies comprise of leading positions in cost minimization, quality and an individual compliance of the consumer's interests [1]. In the modern factory planning process, the formation and application of these core competencies contribute to the "concurrent strategy" of modern enterprises [2]. According to Frese, the concept of competitive strategy hereby constitutes how the involved institutions will determine their corporate

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strategic product-market-combinations in order to reach a competitive advantage against the concurrence.

In contradiction to the classical procedures of the factory planning process, which are described by [3], modern planning projects have to take into account cost and resource reducing procedures that enable an individual and modular design of planning processes. This demand requires both a quantitatively established support of decisions during the planning process provided by Intelligence solutions [4] as well as an integrative mapping of the production process within an overall context of the factory [5, 6].

In practice of factory planning, the specific knowledge of experts plays a decisive role. Based on special experience values, existing planning solutions are evaluated qualitatively in order to adapt the results into tailor made solutions of new planning projects [7]. According to this procedure, ancient planning results and specific knowledge are taken into account to decide, which planning steps have to be taken next. However, this does not lead to sustainable systematics in solving problems of the process design [8, 9]. The gained knowledge cannot be generalized to provide common solutions for similarly natured problems as, during the planning process, concrete decisions are made using specific knowledge that is based on rather qualitative evaluations.

This leads to a central problem in the systematisation of production planning. There are only a few approaches which provide a quantitatively based evaluation of the planning success during the dedicated steps of the planning process. These dedicated steps of planning were introduced by [10] within the Condition Based Factory Planning (CBFP). CBFP hereby serves encapsulated functions to perform the essential steps of factory planning independently. However, the interconnections between these planning modules are mostly based on qualitative models and on a subjective assessment made by the factory planner. Under these circumstances, neither a quantitatively based evaluation of the planning success nor a systematic decision support during planning is realisable.

A promising approach, which supports the realisation of an active decision support tool, is based on so-called Intelligence concepts. These concepts are designed to process information in order to gain a deeper understanding of the underlying processes within a manufacturing enterprise [11]. According to Kemper, there is no clear definition of the Intelligence term, but there are a few approaches to define the term using other technologies. Thus, the Intelligence concept can help filtering information from huge data amounts, can allow fast and flexible data evaluation, can serve as an early warning system or is capable of saving information and knowledge. In terms of production planning, Intelligence concepts are in charge of collecting historical production data to treat the information in a structured way. Consequently, the factory planner is able to access the information in an appropriate form [12].

To enable the transformation of big data into a structured data model, information has to be gathered from different applications. On the one hand, data can be generated by tools, which provide the simulation of single production entities within the factory. These pieces of information often differ significantly. On the other hand, big data pools can be self-generated using modern monitoring systems like the Cyber Physical Systems within a connected infrastructure in terms of the *Internet of Things*.

If this information is aggregated and combined with simulation and historical data, they can e. g. be utilized to map the layout planning of the factory in detail. Various models of segments generated in a similar way can be assessed against each other in order to gain quantitative measures regarding the planning success of each solution. This leads to resilient results and generates data, which can be utilized to build up substantiated decision support systems.

In this context, the central challenge in planning consists in guaranteeing interoperability between all IT systems which are in use to collect, to generate or to aggregate production data. Furthermore, interoperability is needed not only between different simulation processes, but also between different planning modules of the planning scenario to enable an aggregation of different planning modules into one holistic model of the production site. Using this model, an evaluation of different optimization procedures can be performed considering their overall impact on the holistic production planning. If interoperability is not ensured throughout different planning modules, the algorithms and procedures of the optimization cannot be evaluated properly as their impact on other planning modules is not determined. In this case, an assessment of each planning module causes a comparatively high planning effort because all further planning modules have to be fulfilled in a certain order even if changes are performed in only one of them.

An integrative solution for the interoperability issue between heterogeneous, distributed simulations was presented with the concept of adaptive information integration. A framework based on this concept enables the aggregation of input and output data of different simulations so that the data can be stored within one integrated data basis [13]. Upon this data basis, Intelligence solutions can be established, which are based on Business Intelligence approaches and which were introduced as the "Virtual Production Intelligence (VPI)". Hereby, the VPI concept takes into account basic concepts of Intelligence solutions to transfer them into the domain of "Virtual Production". An according web interface provides not only access to the integrated information, but also treatment, manipulation and analysis of process data using various algorithms and heuristics of information technology like Data or Text Mining.

Based on this web interface, cross-functional interconnections as well as interdependencies between different planning modules can be identified and integrated within the evaluation of the holistic factory planning project. In this connection, *Integration* is defined as the functionality and power to interconnect and to harmonize data from various operational data sources [14].

The functionalities provided by these integration methods are used within so-called Data Warehouse (DW) systems, which are able to manage big data from various heterogeneous or even incompatible systems into a consistent structure. Through the integration process into the DW system, dependencies between the different planning modules can be identified. These dependencies can be developed further into general, quantitative *impact relationships* between the evaluations of each planning module within the holistic context of the factory planning project. These results enable the development of methodical, well-founded Intelligence Systems that are able to provide active decision support through the production planning process of the factory.

Within the present work, existing approaches concerning production structure planning are presented in Sect. 2. Section 3 shows the added value of an integrated information basis founded on the VPI Framework. To enable a connection of the VPI Platform into operational levels of producing enterprises through a suitable interface, a web interface will be described in a further step. Finally, the added value of the VPI Platform in terms of factory planning is demonstrated by means of a process chain optimization algorithm within a factory planning use-case. The publication closes with a short conclusion and an outlook to future work.

## 2 State of the Art

### *2.1 Production Structure Planning in Factory Planning*

Production structure planning constitutes a central component of the layout planning. In terms of factory planning, "layout" is defined as the arrangement of operational functional units [3]. In this context, the production structure planning has evolved to one of the core elements of factory planning.

Within factory planning, the term "optimal arrangement" stands for the optimal arrangement in terms of an optimized material flow. The material flow thus serves as the determining optimization criterion of the manufacturing flow [3]. A main reason for this specification consists in the high relevance of material flow costs in production. Due to investigations, the costs of the material flow within metal processing enterprises aggregate up to 10–12 % of the turnover and about 20 % of the manufacturing costs [15, 16]. Structure planning can be performed by using different approaches and levels of detail, e. g. ideal/real layout [3].

Within the present work, the layout planning is restricted to the ideal layout of the arrangement of production entities, particularly on the formation of process chains in terms of the production structure planning. These process chains represent the manufacturing stations that products have to pass until their completion. Due to the fact that the initial segmentation of a factory is mainly based on the quality of process chains, this part of the layout planning is crucial for the whole factory planning evaluation. As a reorganization of the machinery at a later point in time would lead to high costs, it does not take place in most of the cases, even if the current configuration and allocation of production entities is inefficient [17].

There are many computer aided procedures and algorithms to determine the material flow optimal arrangement of production resources. An overview about the existing procedures regarding layout planning was carried out in detail by [18] (see Fig. 1).

Conventional methods like graphical approaches were basically replaced by mathematical and analytical procedures. However, the graphical methods are still in use for

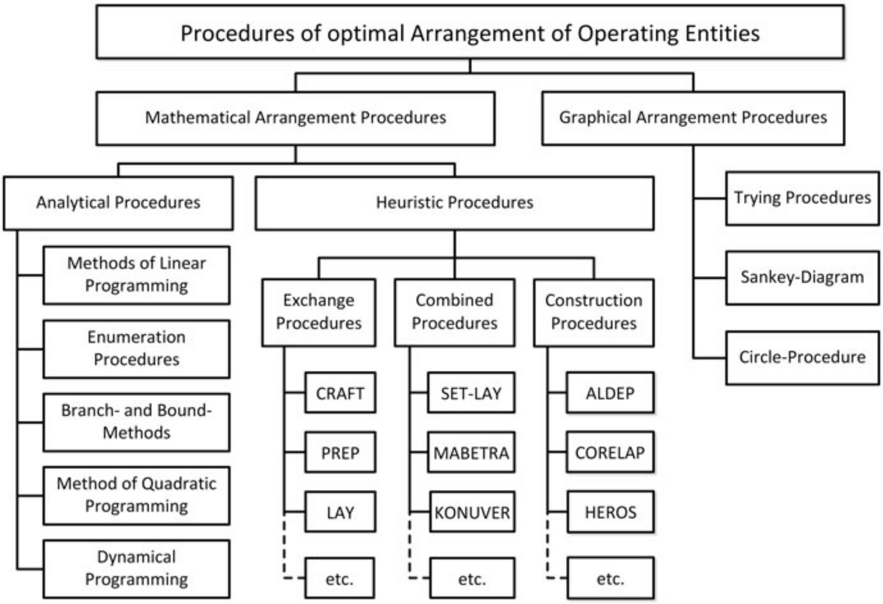


**Fig. 1** Layout planning procedures in production planning

factory planning. The evaluation of the planning results derived from these methods is mostly premised on specific performance figures which were taken into account uniquely for the current planning project. Referring to these performance figures, the factory planning consortium creates a point assessment system that is able to determine qualitative relations between different layout planning scenarios [19].

However, through this procedure, neither a quantitatively resilient evaluation of the factory layouts nor an assessment of the planning results across the borders of a single planning project can be realised. In order to reach this goal, mathematical methods have to be deployed. These methods are adequately explained in the relevant literature [20–22].

In addition to the analytical methods, which allow an exact calculation of the arrangement of resources with regard to a certain target figure, there are also heuristic procedures that are able to perform the layout planning with a reasonable expenditure of time and effort using algorithmic, iterative optimization methods. In order to provide a quantitatively based evaluation throughout the optimization process including a possible adaption of the procedures and methods as described above, an efficient data management and an application of high-performance Intelligence solutions are needed.

## 2.2 Intelligence Approaches within Production Planning

IT aided systems, which are applied in terms of factory planning, aim to provide a quantitatively traceable evaluation and analysis of different scenarios within the planning process and, through this, to ensure a decision support for the factory planner. As the currently utilised IT systems do not allow a holistic mapping of the production planning, innovative concepts with regard to production planning and production operations have to be realised. These concepts include Intelligence approaches and Data Warehouse systems.

A term that has characterized the fields of interest especially during the last years is known as *Business Intelligence (BI)*. In this connection, the term BI is based on the economic point of view of Intelligence solutions. BI was first introduced by Luhn in 1958 and was then mainly promoted by the Gartner Group starting in 1993 (see [23, 24]). In general, BI describes the analysis and usage of enterprise data using Information Technology in order to support decisions that have to be made by the user.

As there is no clear definition of BI at all, the concept was extended by several approaches in order to exploit the BI approach to further applications, e. g. operational BI, Process Intelligence, Corporate Performance Management or Business Performance Management. IT applications that are based on these Intelligence concepts have in common that they aim to *identify*, to *aggregate*, to *extract* and to *analyse* data of entrepreneurial processes [25].

In modern enterprises, data is collected through various instruments starting from applications to automatically generated data during production. One application domain of these advanced functionalities is represented by the term *Cyber Physical Systems (CPS)*. CPS can be regarded as a network of intelligent devices on the operational level. Data generated by these devices is collected and distributed by a network, which is known as the *Internet of Things*. In order to store the automatically generated data as well as data from various, heterogeneous computer applications using one consistent information model, a suitable structure for data integration is needed. The basic concept behind these functionalities is represented by the Data Warehouse systems, which are based on the modeling of multidimensional databases [14]. These database systems represent a necessary instrument to consolidate and to propagate information within enterprises.

The goal of DW systems consists of serving a structured storage of data and of enabling an efficient data access for everyone involved [14]. The founder of this concept characterises DW as a *subject-oriented*, *non-volatile*, *integrated* and *time-variant* database with the intention to support management decisions [26]. To establish DW systems in the field of production planning, their abilities of structuring big data are utilised. Due to the fact that production planning is practically based on models of ancient projects as well as on historical production data, DW systems provide the essential background to implement powerful Business Intelligence solutions.

An application of BI concepts within the management or operational level requires an aggregation of the different tools in use. Therefore, approaches were discussed that can enable a merge of different Intelligence systems. In this connection, the main literature distinguishes mainly between the operational Business Intelligence (OpBI) and Manufacturing Execution Systems (MES). Both systems have in common that they aim to analyse and to coordinate business processes, but in different segments of the supply chain.

In combination with BI technologies like Data Warehousing or Online Analytical Processing (OLAP), OpBI systems are able to serve real-time information [27]. This information is mainly used within sales and marketing [28]. On the contrary, MES serve IT support in the production environment. They are mainly based on engineering oriented concepts with a focus on the organisation of production plants in real-time [29].

A flexible and changeable planning can only be realised if OpBI and MES can be merged. In order to facilitate the transmission and the analysis of data from different sources, a central data storage is needed. The analyses performed using OLAP or Data Mining procedures can be used not only within strategic management, but also within tactical management. In this connection, a centralisation of OpBI and MES using a suitable data platform can lead to more transparency of the operational processes and thus can improve the performance of process design significantly.

# 3 Virtual Production Intelligence Platform

## *3.1 Framework for an Integrative Information Model*

The concepts discussed in Sect. 2, that is the implementation and usage of decision support systems, provide the theoretical basis for the performance of successful production planning processes using Intelligence solutions. In order to provide the required Intelligence functionalities within the field of production planning, Business Intelligence approaches taken from the economic point of view have to be brought into accordance with IT systems that are currently used in production. Hence, in order to use the described approaches within production planning and to obtain an added value in the planning process, a suitable framework is needed to implement these conceptual ideas into a practical planning tool.

With regard to such a framework, the heterogeneity of available software needs to be overcome. Furthermore, the interoperability between distinctive planning modules and between the different Business Intelligence concepts needs to be established. Due to the substantial heterogeneity between the mentioned software systems, no suitable interfaces can be identified between the currently used planning tools. Hence, an interconnection of these software systems cannot be reached on a fundamental basis.

One possible solution for the interoperability issue can e. g. consist in the generation of a standardised data format. However, as earlier investigations have shown, the determination of a common data format is not feasible because of the high complexity of the provided simulation tools and the autonomy of the software developing enterprises [5]. Yet, a promising approach concerning the lack of interoperability among various simulation software consists in the creation of an integrated, canonical data model that takes into account multiple aspects of different data formats and structures and that is thus compatible with all simulation tools [30].

A data basis as described above synchronises the data from different simulations and business processes on the basis of an *Extract-Transform-Load (ETL)* process and thus avoids the adaptation of the whole IT infrastructure. The framework that provides the described functionalities is the *Virtual Production Intelligence (VPI)*, which was firstly introduced by [31]. The underlying platform is hence referred to as VPI Platform. Throughout the according configuration, the framework enables full collection and aggregation of data that is gathered during strategic, planning and tactical-operational activities within an enterprise.

The integration takes place within a two-stage database system. The first database represents some kind of preliminary stage for the data that needs to be integrated. In this database, the data collected during different processes is stored in a comparatively disordered structure. Based on this data basis, an ETL procedure is performed in which the data is integrated into a common, integrative data basis that is represented by a DW system.

### *3.2 Web Application – Interface to the VPI Platform*

In addition to the functionalities provided by the VPI Platform, the accessibility and the control of the platform are of particular relevance. Hence, a suitable interface is needed that provides significant user interaction modules. The goal of this user interface is not only to provide a general overview of all applications that are embedded within the VPI Platform, but rather to aggregate requested data in a role- and user-specific way. The user interface enables people involved in the production planning project to get an overview of all the information that is important for their field of interest. Hence, well-founded and quantitatively resilient decisions regarding the progress of the production planning project become possible. In addition, the planning is supported by the analysis methodologies that are embedded within the information platform. An application that can serve as an appropriate interface to these requirements needs to be built up modularly and has to be able to provide a continuous data processing of the received data.

During the preliminaries of the current work, an appropriate web platform was developed that fulfils all demanded requirements. Using a framework that is based on the GWT-Framework, a web application was developed in order to enable simplified user access. Within this web application, an integration of various pre-implemented widgets can be performed. Based on an XML configuration methodology, rich domain and user specific applications can be built up in terms of modular design principles. Due to AJAX (Asynchronous JavaScript and XML) functionalities and the related facility of asynchronous requests, the web applications that are based on the presented framework can be handled similarly intuitive as a desktop application without having huge disadvantages concerning functionality or performance.

The structure and functionality of such web applications can barely be distinguished from "offline" applications, but they are always up-to-date. Another advantage of using web applications instead of traditional computer applications is, in particular, their independency of the platform or of the computer system. Due to the design of the presented web application, it can be executed within every modern web browser. Hence, an execution of the web application can be performed on every operating system or hardware architecture. In addition, the use of CSS (Cascading Style Sheets) achieves a unified appearance of the application, which is independent of the system in use. Thus, in combination with the web application, the VPI Platform serves as a powerful planning tool for production planning. The concrete added value for production planning is demonstrated on the basis of a use-case within the following section.

## 4 Use-case

### *4.1 Traditional Approaches of Production Structure Planning*

In most cases, the factory planning process is based upon already existing data. This implies that in the conception of a new production structure, the first step normally consists in deriving the basic structures from already existing planning projects. Based on this "historical data", several production configurations are selected and compared to each other.

In the traditional approach, this selection is not entirely based on quantitative data, but also on subjective assessments and experience. In this connection, an evaluation is either entirely qualitative or based on a point system, in which the given "ratings" are derived from the comparison to the planning success of preceding projects [32]. According to Wiendahl [32] and Tompkins [9] layout planning consists not only in the positioning of resources, but also in the definition of functional areas. Thus, different requirements can be imposed on layout planning, especially costs, space utilization, production efficiency, minimization of effort for material transport, transparency, flexibility and changeability as well as information and communication flow or the consideration of restrictions of any kind. The current work is hereby focused on the points space utilization and the minimization of effort for material transport, hence the positioning of resources. An optimization restricted to the points highlighted is also known as the derivation of the ideal layout.

Regarding the optimization of this ideal layout, heuristic approaches are the usual methods of choice. The results of these heuristics are based on qualitative guesses, which afterwards are developed into an "optimal" solution by using semi analytic or iterative mathematical processes. In production structure planning, this proceeding can be organized as follows: At first, the number of segments or production chains is set. Afterwards, according to the requirements, process chains are formed which are able to cover as many products as possible.

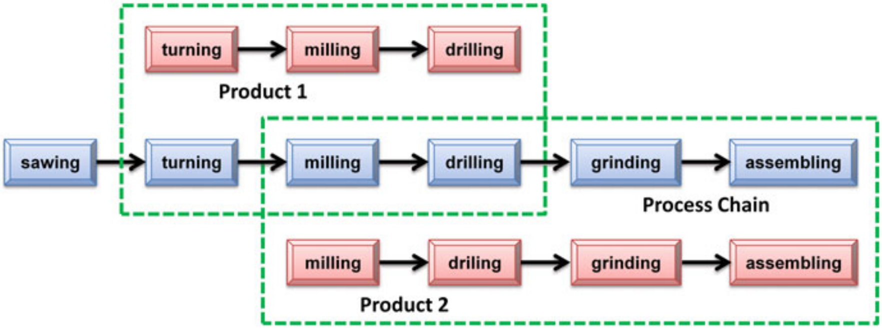


**Fig. 2** Mapping of products on a process chain

A visualization of this approach can be seen in Fig. 2. Each box represents a production entity, whereas the arrows show the flow of material.

This example shows that the central process chain is able to cover all manufacturing steps of both product 1 and product 2. The frames illustrate the process chains' sequences matching the manufacturing chains of the products. An optimal configuration goal is to configure process chains in a way that allows for the production of a maximum number of different products without entailing additional logistical work. Here, the phrase "adding logistical work" means that no step in the production chain needs to be skipped or repeated. Both products shown in Fig. 2 fulfil this condition.

In the practice of production planning processes, it is common that process chains are assumed and further optimized by the use of so called "testing procedures". These procedures are based upon the "expert knowledge" mentioned before and are thereby lacking a quantitative basis. Apart from these "testing procedures", heuristic procedures are used to optimize the production structure. The main difficulty is to integrate planning results into an overall model, which comprise all modules of the production planning. An evaluation of each process chain configuration is therefore associated with high effort as the results of previous planning modules usually have to be entered manually in further evaluation tools.

## 4.2 *Process Chain Optimization Using an Iterative Algorithm*

In the following, it will be shown that using Intelligence tools, especially the VPI Platform, within planning has significant advantages with regard to both heuristic and analytic methods over a dedicated approach to optimization. Therefore, in the present work, an iterative algorithm based upon historical production data was developed, which creates an optimized determination of process chains.

The difference by using the Virtual Production Intelligence Platform instead of a static optimization tool consists in the way of saving the results of the data treatment. According to current methods, one planning step has to be fully completed in order to continue with the next one. Thus, parameters have to be determined even before they can be evaluated holistically. This step-by-step approach causes higher working efforts, especially if parameters of early planning stages have to be changed. That is why the optimization algorithm, which is explained in the following, will be embedded into an information model that allows keeping "elastic" parameters for all steps of the factory planning.

The production data is represented by a list of products that also contains detailed information about the manufacturing steps of each product. This section is intended to describe the algorithm as such. Its position in the overall context as well as its functionality within Decision Support systems are discussed in the following sections. The algorithm performs an optimization, which is based upon historical production data. Therefore, process chains are created out of already existing product data. Afterwards, similarities and regularities inside these process chains are identified by quantitative measures that have been implemented on the basis of counting procedures. Based on these counting procedures, an A-Priori-assessment is made to identify useful process chains.

In a further step, these preliminary main process chains (hereafter referred to as *MainChains*) are evaluated by using statistical and heuristical methods in connection with an iterative optimization algorithm until a certain coverage amount of the products can be achieved. During the computation, it is checked which product chains can be covered by the *MainChains*. These product chains are referred to as *RegularChains* within the program logic. Besides *RegularChains*, the process also identifies product chains that cannot be covered by the *MainChains*. These chains are referred to as *SpecialChains*.

While processing the algorithm, the actual *MainChains* are evaluated within each iteration step first. Subsequently, a switching process replaces certain *MainChains* by process chains determined by a quantitative analysis of the *SpecialChains*. This process is repeated until a certain degree of coverage of all products is assured for the *MainChains*.

## 4.3 Dynamical Layout Optimization Using an ETL Process

The introduced algorithm provides an important contribution to the execution of a production planning project. However, to be evaluated completely, this static optimization of the production structure is not to be considered isolated from other planning modules, but must be placed in an overall context. In the course of the evaluation, a large number of parameter variations may be made in any of the planning modules to achieve an optimal solution for the given problem. The advantage in the use of an "Intelligence System", specifically of the VPI, is that the optimization algorithms are performed for a complete parameter corridor. Thus, the results can be stored in a way, which allows for a direct addressing of the results in the specific optimization of the overall problem.

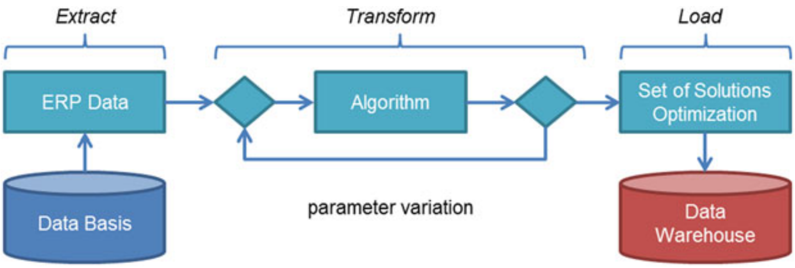


**Fig. 3** ETL process of the Layout Planning

This process is demonstrated using the optimisation algorithm described above (see Fig. 3). The process chain development algorithm was integrated into an *Extract-Transform-Load (ETL)* process commonly used in the context of Intelligence and Data Warehouse concepts. At the beginning of the process, the production data is loaded out of the database and is processed in order to generate process chains (*Extract*). Subsequently, the process chain optimization algorithm is used within the *Transform* process.

One parameter, which can be varied during the layout optimization process, is the number of main process chains (MainChains). According to the number of Main-Chains, the optimization algorithm can e. g. be executed on a span from 3 to 5 MainChains. The choice of an appropriate span can e. g. be based on architectonic limitations or on other factory restrictions. At the beginning of the computation, the user has to set a minimum (numMainChains [= 3]) as well as a maximum number (maxMainChains [= 5]) of considered MainChains. Based on these numbers, the algorithm is performed several times. The results achieved by each run are saved into a multidimensional database using a structure that allows for accessing each "planning scenario" separately.

In addition to a variation of the number of *MainChains*, other parameters can be varied, as well. In a subsequent stage of planning, all results determined by the various algorithms are accessible for the whole parameter corridor that is relevant. Through this, a significant benefit is achieved for the planning process, as modifications can be performed at any time.

Hereby, a user utilizing the web application for a planning process requires no knowledge about the algorithms executed. As the production data as well as the results are processed by the VPI Platform, the user only receives the results that are specifically customized according to his parameters. The Data Warehouse system ensures the implementation of the given results into the holistic process of the production planning project. In further consequence, corresponding to the parameters chosen, the results as well as their dependencies to other modules are included into the complete evaluation of the planning.

## 5 Conclusion and Outlook

By means of a Use-Case derived from production structure planning, the advantages of using Intelligence systems, especially the Virtual Production Intelligence, have been stated. Using the VPI Platform, various boundary conditions and parameters can be taken into account during the modelling of production processes. Furthermore, the VPI Platform enables an integrative, holistic view on the different scenarios of a planning project. The results of single planning modules for different parameters and production configurations can be evaluated within the context of the overall planning. Hence, well-founded quantitative forecasts about the planning result can be made at any point in time during the planning process.

In the context of optimized production planning, the next steps will consist in advancing the presented concepts with regard to both algorithmic procedures and methodical aspects. Thus, firstly, new algorithms and performance indicators will be developed to take into account temporal aspects of the production, as well. Hence, the process chain term will be extended regarding its dimension. The result consists in multidimensional process chains which enable a consideration of temporal dependencies between the manufacturing steps of a product. In this connection, the process times can be taken into account in order to enable a multidimensional production structure optimization. Thus, for example, the process cycle can be harmonized by parallel connections of production entities to minimize waiting times.

As a methodological improvement, the presented concepts of integration and data management will be extended with regard to the different organisational sectors of a manufacturing enterprise. In particular, data exchange should not only be performed between Enterprise Resource Planning systems of the management and the tactical, respectively the planning level, but also between the operational and higher levels.

The resulting challenges for the integration and the data management will be approached by an extension of the Virtual Production Intelligence and the Data Warehousing concepts. In this context, data taken from the operational level (Cyber Physical Systems) will be processed in a way that the information can be integrated productively into Manufacturing Execution Systems as well as into Enterprise Resource Planning systems. Only through the realisation of interoperability between these systems, a holistic digital mapping of the production can be reached. On the basis of this holistic interconnection of data, tools for an active decision support can be derived. These decision support systems ensure a continuous improvement of the production process development by making use of the actual data from the production.

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# The Contribution of Virtual Production Intelligence to Laser Cutting Planning Processes

**Rudolf Reinhard, Toufik Al Khawli, Urs Eppelt, Tobias Meisen, Daniel Schilberg, Wolfgang Schulz and Sabina Jeschke**

**Abstract** In order to facilitate the improvement in product quality and production efficiency, many companies use simulation applications. In turn, they face the challenge of making these applications interoperable. Once the interoperability is established, the challenges of understanding and improving the processes arise. They can be overcome by modeling and analyzing the processes in question. This paper presents a use case scenario from laser cutting. A new concept is introduced addressing the challenges aforementioned. It conforms to the principles of the integration and examination of data and combines virtual production with the goal of gaining knowledge through the analysis of simulated processes.

**Keywords** Application Integration · Data Analysis · Decision Support · Digital Factory

## 1 Introduction

Due to the global price competition, an increasing variance in customer requirements and shorter product lifecycles, production companies in wealthy countries face a growing complexity in their production conditions [1]. In order to address this complexity, the integration of computational techniques in the production environment and its simulation have been promoted in the last two decades. Because of this development and the increasing computing performance in speed and storage, the simulation of the complex production processes, including factory, machine and material, has become possible. But to simulate these processes successfully, they need to be understood properly. As a consequence, instead of being confronted

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with the complexity of the process, the users are confronted with complex simulation applications and processes. To solve this complexity, a process of two steps is executed:

1. Consultancy of available experts for each single manufacturing process.
2. The establishing of communication between these experts to answer specific questions on how to optimize a complete production line.

Additionally, computational techniques and simulation applications are used in the field of production technology [2] to mitigate this complexity. This approach has gained importance in recent years. Due to an increasing computing performance in terms of speed and storage, simulation applications have already changed the execution of research and development (R&D) in an industrial environment.

Although the use and the benefit originating from computational technologies for simulation were demonstrated successfully [3], the implementation of these technologies still seems to be sporadic. It has not become obvious that the simulation can provide a nice overview of a specific manufacturing process and its process domains.

In fact, both the industrial developer for manufacturing machines and the machine operator face essentially the same problem as a navigator in real space that is to find points-of-interest in the configuration space of a single machine or of a complete production line. Crucial differences consist in the fact that the required map (in case of manufacturing a process map) has more than two or three dimensions and that there are few to no "cartographers" who have created maps describing the relevant process domain space.

Exploratory analysis providing the investigation of manufacturing processes resp. its configuration space may be a helpful tool for mastering the variety of dimensions which have to be taken into consideration. With an additional visualization component, it supports developers of manufacturing technologies or even machine operators through the-dimensions of design resp. the configuration space. A prototypic implementation of such an exploratory data analysis tool in combination with selected methods of analysis, such as a multidimensional, multi-objective optimization, is currently in progress.

By now, a digital model of this prototype is drafted containing a description of its essential characteristics instead of engineering a concrete prototype at an early stage of product design. In a further step, this model is passed to a simulation application to predict the prototype's characteristics that may have changed after having passed the manufacturing step. The usage of these digital models is subsumed under the notion of virtual production, which contains "the simulated networked planning and control of production processes with the aid of digital models. It serves to optimize production systems and allows a flexible adaptation of the process design prior to prototype realization" [4, 5].

This paper introduces an integrative concept that applies solutions for the analysis of data within the field of virtual production. This concept provides for the integration, analysis and visualization of data that are aggregated along the simulated process chains of production engineering. The concept's aim is to support the understanding of considered processes by providing appropriate analyzing methods. Because of its application to integrative virtual production processes, it is called Virtual Production Intelligence (VPI). This paper illustrates the development of the concept of Virtual Production Intelligence and its exemplary application in the field of laser cutting technology. Section 2 presents the introduction of VPI into laser cutting R&D. In Sect. 3, requirements arising from the analysis of these manufacturing processes are explored. Section 4 describes how to meet these requirements. A conclusion and an outlook are given in Sect. 5.

## 2 Virtual Production Intelligence: Definition and Object

Nowadays, various simulation applications exist within the field of virtual production, which allow for the simulated execution of manufacturing processes like heating and rolling. Herein, different file formats and file structures were independently developed to describe digital models. Through this, the simulation of single aspects of production can be examined more easily. Nevertheless, the integrative simulation of complex production processes cannot be executed without large costs and time efforts as the interoperability between heterogeneous simulation applications is commonly not given.

One approach to overcome this challenge is the creation of a new standardized file format, which supports the representation of all considered digital models. However, regarding the variety of possible processes and application domains, such an approach leads to a highly complex data format. Its potential and expressiveness is not required in most of its use cases. Its comprehension, maintenance and usage, again, require large costs and time efforts. Furthermore, necessary adaptations and extensions take a lot of time until their implementation is finished [6, 7].

Another approach considers the usage of concepts from data and application integration avoiding the definition of a uniform standard. Within this approach, the interoperability between the simulation applications is guaranteed by mapping the aspects of different data formats and structures onto a so called canonical data model [8, 9]. Newer approaches extend these concepts with regard to semantic technologies by implementing intelligent behavior into such an integrative system. This approach is called Adaptive Application and Data Integration [10].

As a consequence, new possibilities concerning the simulation of whole production processes emerge, which allow the examination of different characteristics of the simulated process, e. g. material or machine behavior. With regard to the analysis of the integrated processes, new questions arise as methods for the analysis of the material or machine behavior mentioned above cannot be transferred to the analysis of the corresponding integrated process. A further challenge comes up as soon as suitable user interfaces are added, which are necessary for the handling of the integrated process and its traceability.

Similar questions emerge whilst the analysis of enterprise business data. Applications giving answer to such questions are in many cases subsumed under the notion of Business Intelligence. These applications have in common that they identify, aggregate, extract and analyze data within enterprise business applications [11, 12].

The virtual production aims at an entire mapping of the product as well as of the production processes within a numerical model. Thereby, the mapping should comprise the whole lifecycle of the product and of the production system [13]. Within an enterprise, the virtual production is established by employees, software tools such as Product-Lifecycle-Management applications (PLM applications) and organizational processes [13].

The demanded possibilities for analysis serve the purpose of gaining knowledge by examining already completed planning processes. As already mentioned, the term "intelligence" is commonly used to describe activities that are linked to those analyses. Software tools, which support the analysis and the interpretation of business data, are subsumed under the term "Business Intelligence".

As this term can be defined in different ways, at this point, the basic idea of "Business Intelligence" will be pointed out [14]: A common feature of the definitions referred to consists in the aggregation of relevant data from different data sources, which are applications within a company, into data storage, which is available whenever needed. The transmission of data taken from the application data bases into this central data storage is realized by the well-known extracting, transforming and loading process (ETL). Though being common, concepts of intelligence solutions like those employed for reporting or customer relationships management (CRM) are not considered in this paper, but the integration and analysis of data. This decision is taken due to the lacking necessity of reporting and customer relationship management within the planning of laser cutting processes.

Requirements for a system that supports the planning process are described in Sect. 3.1. In particular, the idea of Business Intelligence can be subsumed as below:

- Interoperability: Facilitating the interoperability between applications in use.
- Analytical capabilities: Systematic analyses providing the recognition of potentials towards optimization and delivering fundamental facts for decision support.
- Alternative representation models: Taylor made visualization for the addressed target group, which provides an appropriate analysis.

In order to find a solution, which fulfills the requirements mentioned above, a concept formation is needed that addresses the field of application, that is, in this case, the virtual production already mentioned above as well as the aim of gaining knowledge. This aim is also addressed by the term "Intelligence". The concept formation will take into account approaches, methods and concepts. These will contribute to the gaining of knowledge with regard to/concerning the processes executed within the field of virtual production. Therefore, the concept formation results in the notion of Virtual Production Intelligence.

In [15], an exemplary use case from the field of "factory planning" can be found, in which data integration methods belonging to the idea of Virtual Production Intelligence have been applied.

# 3 Virtual Production Intelligence Concepts Applied in the Field of Laser Cutting

## *3.1 The Laser Cutting Process*

Laser cutting is a thermal separation process widely used in shaping and contour cutting applications. The industrial most relevant laser cutting process is the fusion metal cutting process, as the cutting of large metal sheets into smaller pieces with specified contours is addressed in many branches of manufacturing industry. Laser cutting has the advantage over conventional cutting techniques that it is a very fast and at the same time very accurate technology with the optical tool laser not being exposed to any wear.

There are, however, gaps in understanding the dynamics of the process, especially with regard to issues related to cut quality (cf. Fig. 1). It was found that the modeling and simulation of the laser process can provide that understanding without the need for executing a lot of experiments [16].

The ablation process in fusion metal cutting is mainly based on thermodynamics and hydrodynamics, as the absorbed laser energy is converted to heat, which melts the material. In the end, this melt is driven out of the cut kerf by a gas jet coming out of a cutting nozzle coaxially aligned with the laser beam.

There are some criteria that are of major interest in the context of this manufacturing technology, such as cut quality, adherent dross and maximum cutting speed.

The modeling of a laser cutting process requires the modeling of at least three entities at the same time. The three elements involved in cutting are the gas jet, the laser beam and the material to be cut. Therefore, it is evident that the modeling of the cutting gas flow, the radiation propagation and the ablation of the material (in fusion cutting: removal by melt ejection) have to be accomplished as well as the numerical implementation of these models. This was already put into practice. So, nowadays, there are appropriate models available [16].

## *3.2 Exploration of Parameter Domains in Laser Cutting Supported by Virtual Production Intelligence*

In modeling and simulation of manufacturing processes, the state of the art incorporates the performance of an individual simulation. The simulation is characterized by a high dimensional input parameter set. Each parameter lies in its own range, and thus forming the parameter domain space. The quality results, which are totally dependent on the numerical model and the parameter set, play an important role in understanding and optimizing the process.

Conversely, gaining knowledge and understanding the process from just having simulation results of discrete points in the parameter space is not enough. These points

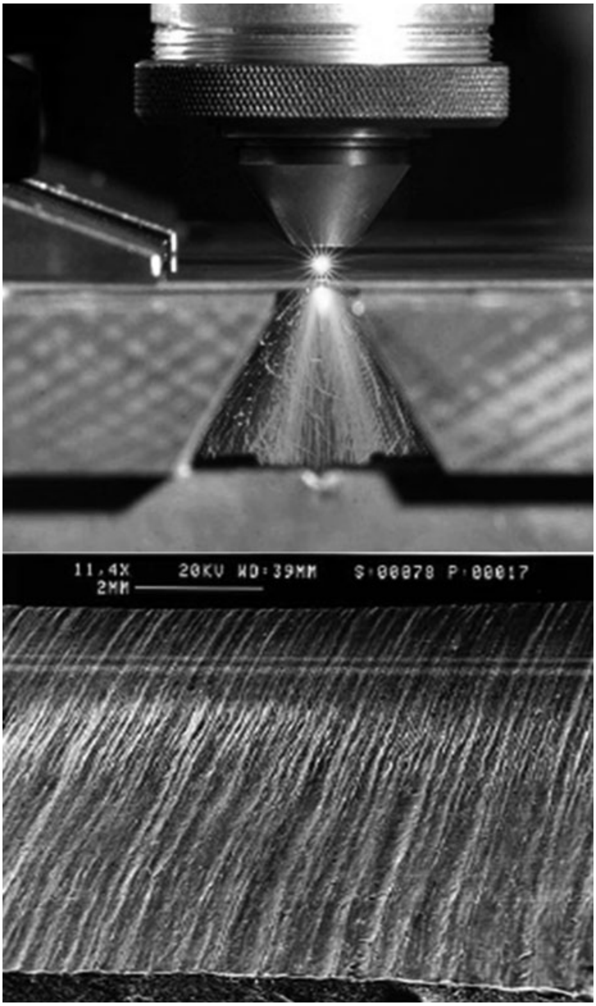


**Fig. 1** The laser cutting process (*top*) and the resulting cutting kerf (*bottom*)

should be reasonably connected to each other to form a knowledge base system that can be executed by the users.

The knowledge base system, which is characterized by a simple surrogate of process parameters and process quality, makes it easier and practical for the user to explore any complicated, highly dimensional parameter systems. This is done either by the identification of solution properties that contribute well to any design optimization process or by the visual exploration of certain parameter domains.

The process, in which the discrete points are transformed into a connected continuous map, is called metamodeling. Metamodeling defines a procedure to analyze and to represent complex physical systems using noncomplex, fast mathematical designs to create cheap numeric surrogates that describe cause-effect relationships between setting parameters as input and product quality variables as output.

The metamodeling procedure mainly relies on the training data which has to be collected at different sampling points. In order to choose the best coordinates for the sampling points, techniques called design-of-experiments-method (DOE) [17] are used. However, a growing multidimensional parameter space leads to a rising complexity. In this paper, the initial training set is chosen to be random and sparse. It is initialized using a space filling designs method, e. g. orthogonal array or Latin hypercube design (LHD).

As shown in Fig. 2, the creation and extraction of simulation data is shown with appropriate physical numerical models: Spatially and time resolved simulations provide whole distributions of physical properties (e. g. temperature distributions), which need to be reduced to criteria significant for the process (i. e. scalar quantities). In laser cutting, these characteristic criteria are extracted from a cutting model such as [18, 19] and are then potentially transferred to a modeling database. The following step consists in mapping the discrete input process parameters and the output process quality through a numerical approximation. The approximation can be executed with the help of various techniques like radial basis function network (RBFN) [20, 21], Taylor series expansion, Kriging model [22, 23] or artificial neural networks (ANN) [24]. The initial metamodel is considered to have poor quality because of the small number of training data sets. Thus, the metamodel is constructed repeatedly by adding new sampling points to the training data until the quality becomes sufficient. In order to obtain a better quality the most important requirement is instantaneously adding new sampling points, first around the optimum of the metamodel and second around the sparse region in the design variable space [22]. A global optimum for multidimensional parameters can be achieved with the help of computational-intelligence (CI)-algorithms, for example genetic algorithms [25], which address complex real-world problems, especially in providing solutions for complicated and/or inverse problems [26]. As a result, the new evolutionary metamodeling uses the concept of evolution control to build up not only the optimal but also the minimal metamodel training data base necessary for the best approximation of the parameter-criteria-relationship possible.

In order to gain insights into the laser cutting process with the aim of optimizing it (e. g. gas savings or energy savings without any quality loss of the cut product), an exploration process is necessary. The exploration process is based on an interactive visualization platform and on optimization algorithms for solving inverse problems. Here, the metamodel is used because of its simplicity and evaluation speed. A further important component of the high dimensional exploration, is the decomposition of the underlying parameter space, as it introduces the process domains from which a typical machine configuration is chosen. This could be approached, for example, by the computation of the Morse-Smale complex from unorganized scattered data [27].

The Morse-Smale complex provides a topologically meaningful decomposition of the domain by finding all of the global and local maxima and minima at the beginning of the process. Decomposing and visualizing the domain will help to acquire a qualitative understanding of the laser cutting process. Moreover, it will help to find a feasible configuration space, which is in accordance with potentially pre-defined quality criteria.

**Fig. 2** The VPI workflow of laser cutting process

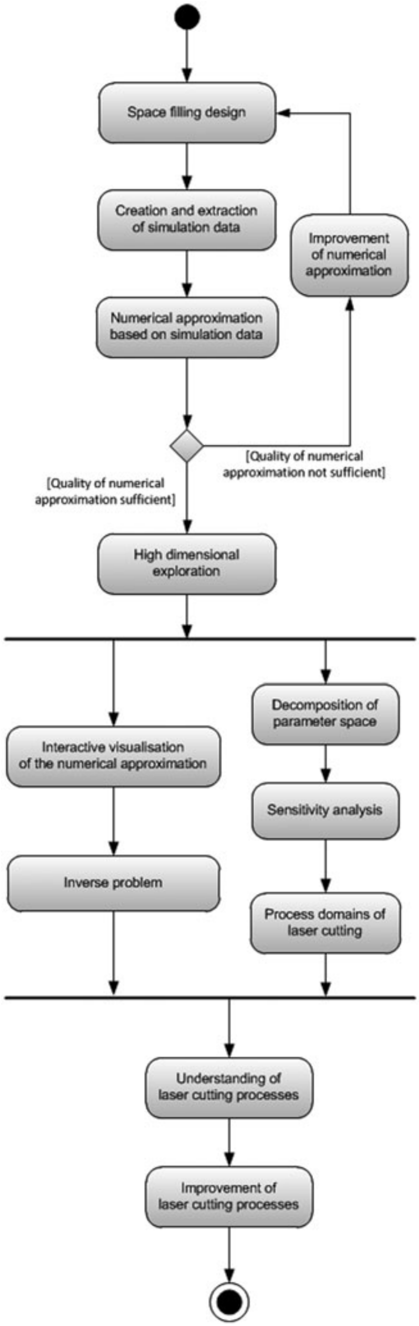

**Table 1** Exemplary input quantities of an examined laser cutting process

| | PL.W. | focus.m. | rbd.mm. | wkerf.mum. |
|---|---|---|---|---|
| 1 | 1000.00 | −10.000000 | 0.0150000 | 562.264 |
| 2 | 5655.17 | −10.000000 | 0.0150000 | 769.176 |
| 3 | 5137.93 | −9.310340 | 0.0150000 | 733.526 |
| 4 | 4620.69 | −8.620690 | 0.0150000 | 699.018 |
| 5 | 4103.45 | −7.931030 | 0.0150000 | 664.268 |
| 6 | 3586.21 | −7.241380 | 0.0150000 | 629.733 |

The methods introduced above result in an iterative enhancement of the metamodel function which serves as an effective approach of mapping input-output relationships for detecting the influence of input parameters on the output criteria. Besides, they assist in the decomposition of the whole high-dimensional parameter space in so-called process domains. Within these domains, numerous complicated sub-processes (e. g. the evaporation-driven melt-ejection domain should be separated from the gas-jet-driven one in laser cutting) can be better understood and optimized.

Thus, there is the need to propagate output data from simulation applications. These data describe simulated laser cutting processes, which are the multidimensional interaction of input and output quantities.

So the need of multi-dimensional analysis methods to examine the simulated processes arises. The following chapter contains a description of the actions that need to be taken to meet the requirements summarized above.

# 4 Integration and Analysis of Process Simulation Data

## *4.1 Integration Process and the Data Model*

Simulation results are written out into output files whose syntax is kept in a table. In doing so, it can be guaranteed that the output data is kept in a human readable form. The columns' names describe both, input and output quantities as well as the unit to measure the corresponding quantity. Table 1 illustrates the first rows of such a file describing an examined cutting process. Four columns have been selected to show exemplary quantities. Their heads describe the quantity's name and its unit.

To ensure the integrity of data, the user must be aware of the units used within the simulation application. In the case this is not given, appropriate computation steps have to be performed before integrating the data containing the application results into the data storage. This usage can be varied by the application's operator. The selection of a differing unit for the measuring of the laser lens' focus during the examination of one laser cutting process causes the recalculation of the extract data, so that the given quantity fits to the new unit. As a consequence, the computation of adapted values has to be performed before the integration of data is executed.

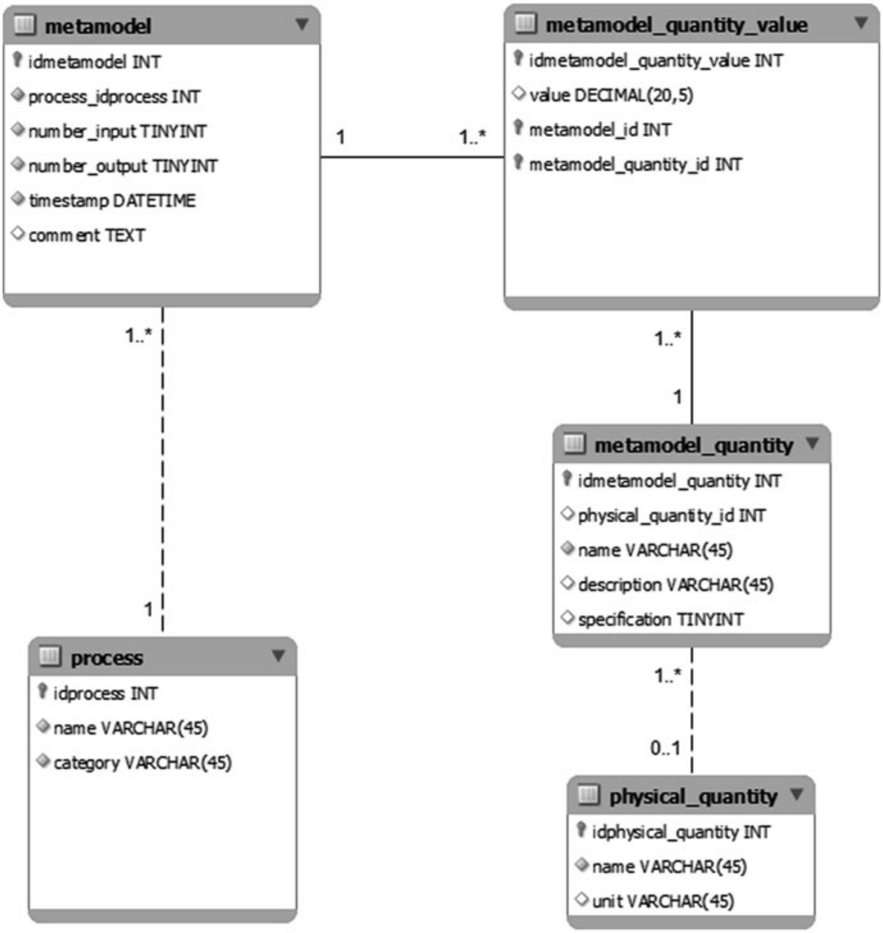


**Fig. 3** Data model for the integration and analysis of laser cutting data in UML-notation

The data for analysis is prepared by making use of five tables, which are depicted in Fig. 3.

Each manufacturing process, which was already analyzed, determines a row in the table process. For the later purpose to build up a history of all examined processes, each process is named properly. Naming policies are not considered in the data model and have to be implemented by the use of appropriate ontologies. This approach ensures the separation of content and data. The table also contains an attribute category to guarantee the generality for manufacturing processes, which are examined by making use of the method of metamodeling as defined in Sect. 3.1.

During the examination of a laser cutting process, several discrete simulation data are considered. To ensure this relationship between examined process and corresponding simulation data within the data model, the table metamodel contains a foreign key with the id of the associated process. The table manages the inputs and the outputs for a discrete set of input and output data as already described in Sect. 3.2. To facilitate the versioning within the considered simulation data by examining a single process, each row within the table metamodel has a timestamp, which contains both, information about the point in time at which the simulation data was created as well as a comment for the process analyst.

Rows in the table *metamodel-quantity-value* represent each value involved in an examined process. A row in this table always corresponds to a single row in the table *metamodel*.

Each involved quantity within a numerical simulation generates a row in the table *metamodel-quantity*. It can either serve as an input for the numerical approximation (parameter) or as an output for the numerical approximation (criterion).

To differentiate between these two cases, the descriptor "specification" is used by the following convention: specification = 0 means input, specification = 1 means output. By following this approach, future specifications such as boundary conditions can also be considered for a numerical approximation and can be mapped into this data model without the need of creating a new attribute for this table.

Each input or output quantity has its abstracted physical quantity, which is managed in the table *physical_quantity*. The following case might serve as a simple example: the diameter of a laser jet corresponds to the physical quantity "length" as well as to the cutting length of the product. The presented approach for the modeling of data within an examined laser cutting process facilitates the implementation of requirements for other manufacturing processes explored by the method of metamodeling.

### *4.2 Analysing the Data: Methods and Tools*

As already described in Sect. 3.2, the aim of the analysis is to determine the relationships of input variables and measured output values in a high dimensional parameter space. It can be described as follows: Assume a specified target criterion. What are the parameters involved to obtain this criterion? This problem is also known as the inverse modeling problem. Due to the high dimensionality that is characteristic of the examined data sets, dimension reduction is a requirement, which also has to be met.

Since the relationships between input and output cannot be described in a formal way, the interactive exploration of data is the approach most promising to investigate these relationships. To facilitate the exploration, an online tool is under development. The user interface consists of various manipulation and variation tools enabling the user to obtain insights within the data.

Since the philosophy of Virtual Production Intelligence contains, in particular, integration and collaboration, an online tool is build providing the usage of already developed and stable solutions in the field of data analysis. Within the last years, the programming language R [28] was used more frequently; one of the reasons is the fact that this programming language is not proprietary.

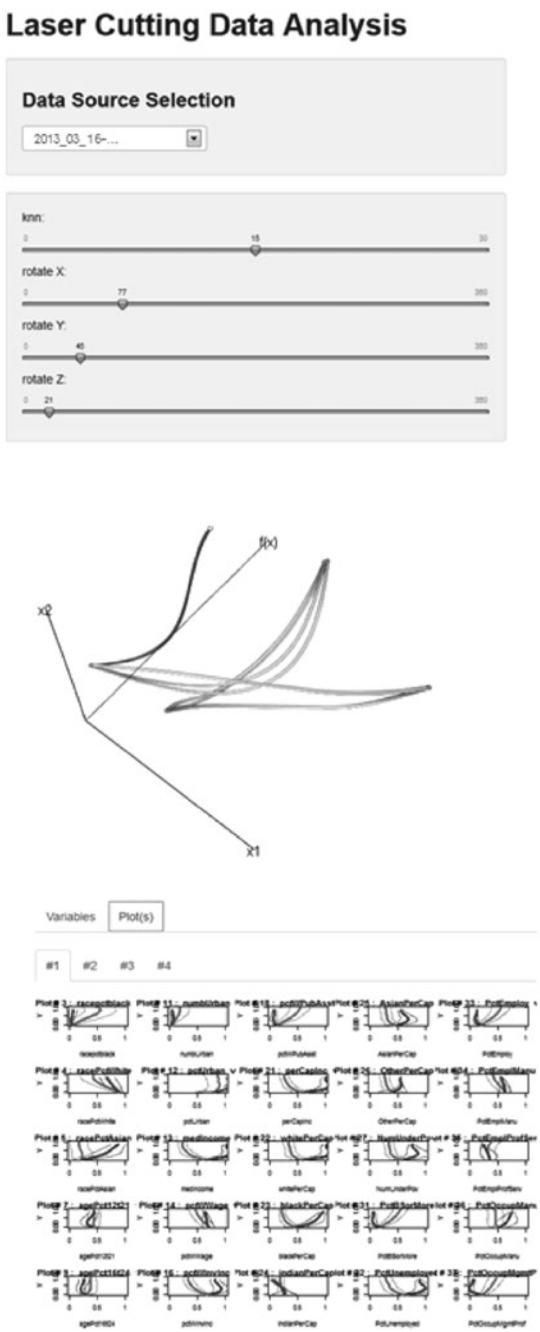


**Fig. 4** Screenshot of the user interface for online analysis of simulation data

The provision of a fast communication with less latency is a crucial requirement. This requirement is met by servers using the web socket protocol [29] enabling the bidirectional communication between client and server.

To build up a prototypical but stable web application as fast as possible, which provides the integration of data analysis methods written in R, the web application framework "shiny" [30] has been used. It is based on the usage of the web socket specification.

The implementation of promising statistical methods like clustering, dimension reduction and singular value decomposition is initiated and first results encourage the implementation of further methods. Most of these are available via packages written in R. One of these packages subsuming many benefits is the Morse-Smale-Package [27], which is also available at the VPI-platform. Figure 4 shows a screenshot of the implementation of the Morse-Smale-Package as a web application with the help of the "shiny" framework mentioned above. In future development steps, further analytical methods will be available for the examination of process data sets. This will be realized by invoking web services with appropriate interfaces to the implementing language, such as C, Python or R.

## 5 Summary and Outlook

This paper presented the general idea of Virtual Production Intelligence and its application in the planning of laser cutting processes. Generally, its aim is to support processes within the Virtual Production by providing the integration and the analysis of data generated along the planning of production processes. In particular, the analysis requires the usage of appropriate methods and tools.

One concrete application of this idea consists in the use of the computational technologies mentioned above for the R&D of the laser cutting process. During the examination of these processes, numerical methods have a huge impact on the planning. Requirements on data integration and analysis were described and it was pointed out how these requirements can be met. Furthermore, an online analysis tool was described, which is suitable for the analysis of high dimensional data sets.

Further progress will contain the elaboration of additional methods for the refinement of numerical approximation and the identification of suitable stochastic methods. In both cases, an implementation for the validation of the identified methods is intended to show how the additional methods have improved compared to the methods used in the past.

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# Virtual Production Intelligence – A Contribution to the Digital Factory

**Rudolf Reinhard, Christian Büscher, Tobias Meisen, Daniel Schilberg and Sabina Jeschke**

**Abstract** The usage of simulation applications for the planning and the designing of processes in many fields of production technology facilitated the formation of large data pools. With the help of these data pools, the simulated processes can be analyzed with regard to different objective criteria. The considered use cases have their origin in questions arising in various fields of production technology, e. g. manufacturing procedures to the logistics of production plants.

The deployed simulation applications commonly focus on the object of investigation. However, simulating and analyzing a process necessitates the usage of various applications, which requires the interchange of data between these applications. The problem of data interchange can be solved by using either a uniform data format or an integration system. Both of these approaches have in common that they store the data, which are interchanged between the deployed applications. The data's storage is necessary with regard to their analysis, which, in turn, is required to obtain an added value of the interchange of data between various applications that is e. g. the determining of optimization potentials. The examination of material flows within a production plant might serve as an example of analyzing gathered data from an appropriate simulated process to determine, for instance, bottle necks in these material flows.

The efforts undertaken to support such analysis tools for simulated processes within the field of production engineering are still at the initial stage. A new and contrasting way of implementing the analyses aforementioned consists in focusing on concepts and methods belonging to the subject area of Business Intelligence, which address the gathering of information taken from company processes in order to gain knowledge about these.

This paper focusses on the approach mentioned above. With the help of a concrete use case taken from the field of factory planning, requirements on a data-based support for the analysis of the considered planning process are formulated. In a further step, a design for the realization of these requirements is presented. Furthermore, expected challenges are pointed out and discussed.

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**Keywords** Application Integration · Data Analysis · Decision Support · Digital Factory

## 1 Introduction

Due to the global price competition, the increasing ranges of varieties and customer requirements as well as resulting shorter product lifecycles, production companies in high wage countries face a growing complexity within their production circumstances [1]. Methods and concepts which are used in order to overcome this complexity often fail to address the whole production process. Therefore, solutions are needed, which allow a holistic and integrated view of the relevant processes in order to achieve an increasing product quality, production efficiency and production performance [2].

Within the last years, the usage of simulation applications in the field of production technology became a measure with a growing significance to overcome the complexity mentioned above. Because of the increasing computing performance concerning speed and storage, these simulation applications changed the way of carrying out planning and preparing activities within production. So, instead of engineering a concrete prototype at an early stage of product design, a digital model of this prototype is drafted containing a description of its essential characteristics. In a further step, this model is passed to a simulation application to predict the prototype's characteristics that may have changed after having passed the manufacturing step. The usage of these digital models is subsumed under the notion of virtual production, which "is the simulated networked planning and control of production processes with the aid of digital models. It serves to optimize production systems and allows a flexible adaptation of the process design prior to prototype realization." [3, 4]

Nowadays, various simulation applications exist within the field of virtual production, which allow for the simulated execution of manufacturing processes like heating and rolling. Herein, different file formats and file structures were independently developed to describe digital models. Through this, the simulation of single aspects of production can be examined more easily. Nevertheless, the integrative simulation of complex production processes cannot be executed without large costs and time efforts as the interoperability between heterogeneous simulation applications is commonly not given.

One approach to overcome this challenge is the creation of a new standardized file format, which supports the representation of all considered digital models. However, regarding the variety of possible processes, such an approach results in the creation of a complex, standardized file format. Its comprehension, maintenance and usage, again, require large costs and time efforts. Furthermore, necessary adaptations and extensions take a lot of time until their implementation is finished [5, 6].

Another approach considers the usage of concepts from data and application integration avoiding the definition of a uniform standard. Within this approach, the interoperability between the simulation applications is guaranteed by mapping the aspects of different data formats and structures onto a so called canonical data model [7, 8]. Newer approaches extend these concepts with regard to semantic technologies by implementing intelligent behavior into such an integrative system. This approach is called Adaptive Application and Data Integration [9, 10].

As a consequence, new possibilities concerning the simulation of whole production processes emerge, which allow the examination of different characteristics of the simulated process, e. g. material or machine behavior. With regard to the analysis of the integrated processes, new questions arise as methods for the analysis of the material or machine behavior mentioned above cannot be transferred to the analysis of the corresponding integrated process. A further challenge comes up as soon as suitable user interfaces are added, which are necessary for the handling of the integrated process and its traceability.

Similar questions emerge whilst the analysis of enterprise data. Applications giving answer to such questions are subsumed under the notion of Business Intelligence. These applications have in common that they identify, aggregate, extract and analyze data within enterprise applications [11, 12].

In this paper, an integrative concept is introduced that transfers the nature of these solutions to the field of application of production engineering. It contains the integration, the analysis and the visualization of data, which have been aggregated along simulated process chains within production engineering. In respect to the concept's application domain and its aim to contribute to the gaining of knowledge about the examined processes, it is called Virtual Production Intelligence. In order to illustrate this approach, in Sect. 2, a use case scenario from factory planning is taken into consideration. In Sect. 3, requirements are listed, which arise from the use case scenario described in Sect. 2. The realization of these requirements makes it necessary to create new concepts, which are presented in Sect. 4. Section 5 contains a description of expected challenges that come up while realizing the requirements defined in Sect. 3. This paper concludes with a summary and an outlook on a further use case.

## 2 Use Case Factory Planning

The notion of virtual production comprises the planning of processes that are characteristic for factory planning. In this chapter, a scenario taken from the field of factory planning is introduced, which follows the concept of Condition Based Factory Planning (CBFP). This concept facilitates an efficient planning process without restricting its flexibility by making use of standardized planning modules [13]. With the help of this scenario, it is pointed out which data are aggregated and which questions are raised concerning the integration, analysis and visualization of data within the planning process of a factory aiming at the support of this planning process. In the following, after having illustrated the use case, the examination of the planning process aforementioned is subsumed under the notion of Virtual Production Intelligence.

The concept of CBFP is employed to analyze factory planning scenarios with the aim of facilitating the factory planning process by decomposing it into single

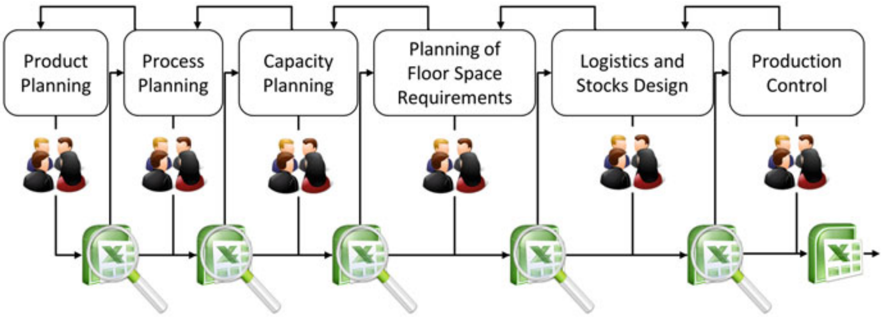


**Fig. 1** Exemplary non-linear factory planning process following CBFP

modules [13]. These modules address various aspects within factory layouting like material flow or logistics. Because of the modular procedure, the characteristical non-linearity of planning processes can be mapped onto each process' modeling.

Within various workshops, requirements concerning the future factory are gathered in collaboration with the customer. For this purpose, table calculation and simulation applications are employed. Subsequent to these workshops, the gathered data are evaluated by one of the factory planners, who participated in the workshops, and suitable planning modules belonging to CBFP are identified. Thereby, different scenarios of the factory's workload are examined to guarantee the future factory's flexibility. Figure 1 illustrates this procedure focusing on the exemplary planning modules Product Planning, Process Planning, Capacity Planning, Planning of Floor Space Requirements, Logistics and Stock Design as well as Production Control.

Although the planning process is supported by the planning modules from CBFP, a significant disadvantage remains as the procedure is vulnerable concerning input errors committed by the user. Furthermore, the automated analysis of gathered data is complicated, due to the lack of a uniform data model.

The support of the planning process is based on a data model, which fulfills the planning modules' requirements. Thereby, the collection of data is performed by making use of familiar applications. Each analytical step, e. g. the calculation of different scenarios of the factory's workload, is computed on a dedicated server by the factory planer during the evaluation phase between two workshops. One advantage of this procedure is the coherent data handling during the entire planning process. Because of this coherent data handling, the design output can be made available for uninvolved and, in particular, new employees as well as for the executives after having finished a planning process. An interactive visualization allows for an explorative analysis of the simulation application's output. Such an integrative solution facilitates the location of possibilities for optimization within the examined processes. As an organizational consequence and a lasting effect, the experiences made during the implementation of optimization processes can be employed with regard to the composition of best practices for planning projects within the planning company. The implementation of the integrated solution is depicted in Fig. 2.

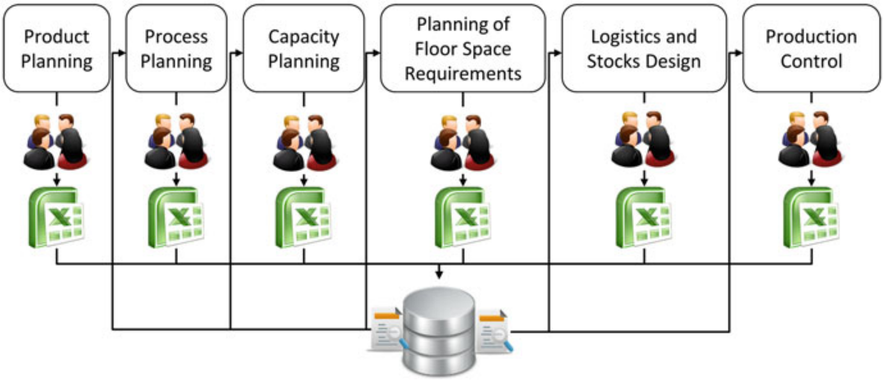


**Fig. 2** Exemplary factory planning process following CBFP, supported by an integrative solution

As a consequence of the integrated consideration, different fields of employment emerge, for instance the immersive visualization of a digital model of the future factory within a Cave Automatic Virtual Environment (CAVE). This immersive visualization provides the possibility of inspecting the future factory virtually. In doing so, the customer gets the option to feedback the current state of the factory's planning process, which in turn leads to an improved satisfaction regarding the planning's outcome. The creation of the interoperability between the involved applications, on the one hand, and the integrative data handling and analysis, on the other hand, results in the provision of such a solution without generating larger costs and time efforts.

Furthermore, the usage of this solution allows for the examination of different outcomes within a planning problem, e. g. the distribution of machines within a hall and the corresponding planning aspects like logistics or staff security, on a homogeneous data basis. Such a solution might also be adapted to the requirements of another field of application, like marketing, if the attention is directed to the presentation of the planned area rather than to the computing accuracy. Another field of application is the training effort for new employees. Its reduction is an important aim due to high wage costs. In this context, different views adapted to relevant questions of new employees can be used, which comprise the complete and detailed presentation of the current project as well as of past projects.

The scenario described above, which includes methods from factory planning, illustrates how the support of the planning process can be designed. In this scenario, the integration, the analysis and the visualization of data gathered during the planning process is realized. The following chapter comprises a description of requirements that need to be fulfilled when dealing with a system that provides the aforementioned support of the planning process.

## 3 Requirements on an Integrative Solution Based on an Analysis for Process Data

The virtual production aims at an entire mapping of the product as well as of the production within a model for experimental purposes. Thereby, the mapping should comprise the whole lifecycle of the product and of the production system [14]. Within an enterprise, the virtual production is established by employees, software tools such as Product-Lifecycle-Management applications (PLM applications) and organizational processes [14].

The demanded possibilities for analysis serve the purpose of gaining knowledge by examining already completed planning processes. The term “intelligence” is commonly used to describe activities that are linked to those analyses. Software tools, which support the analysis and the interpretation of business data, are subsumed under the term “Business Intelligence”.

As this term can be defined in different ways, at this point, the basic idea of “Business Intelligence” will be pointed out [15–17]. A common feature of the definitions referred to consists in the aggregation of relevant data from different data sources, which are applications within a company, into a central data storage. The transmission of data taken from the application data bases into this central data storage is realized by the well-known Extracting, Transforming and Loading process (ETL). Subsequently, the data are arranged in more dimensional data cubes following a logical order. In doing so, a company’s IT is divided into two different categories:

- Operational: This category contains applications customized for e. g. the accounting department, the purchasing department or the production department of a company.
- Analytical: In this case, the category contains applications for the analysis of data arising from the applications mentioned in the operational category.

The fact that operational processes are not influenced by analytical processes can be regarded as an advantage of this division.

Requirements for a system that supports the described planning process in Sect. 2, in particular the data and application integration, and which additionally follows the idea of Business Intelligence can be subsumed as below:

- Interoperability: Facilitating the interoperability between applications in use.
- Analytical abilities: Systematic analyses providing the recognition of potentials towards optimization and delivering fundamental facts for decision support.
- Alternative representation models: Taylor made visualization for the addressed target group, which provides appropriate analysis facilities based on a uniform data model.

In order to find a solution, which fulfills the requirements mentioned above, a concept formation is needed that addresses the field of application, that is, in this case, the virtual production already mentioned above, as well as the aim of gaining knowledge. This aim is also addressed by the term “Intelligence”. The concept formation will take into account approaches, methods and concepts. These will contribute to the achievement of objectives concerning the gaining of knowledge with regard to the processes executed within the considered field of application, which is the virtual production. Therefore the concept formation results in the notion of Virtual Production Intelligence.

This notion will be described in the following section.

## 4 Objectives of the Virtual Production Intelligence

The Virtual Production Intelligence (VPI) is a holistic, integrated concept that is used for the collaborative planning of core processes in the fields of technology (material/machines), product, factory and production planning as well as for the monitoring and control of production and product development:

- Holistic: Addressing all of the product development's sub processes.
- Integrated: Supporting the usage and the combination of already existent approaches instead of creating new and further standards.
- Collaborative: Considering roles, which are part of the planning process, as well as their communication and delivery processes.

The VPI aims at contributing to the realization of the digital factory, which is defined as follows:

Digital factory is the generic term for a comprehensive network of digital models, methods and tools – including simulation and 3D visualization – integrated by a continuous data management system. Its aim is the holistic planning, evaluation and ongoing improvement of all the main structures, processes and resources of the real factory in conjunction with the product [4].

The concept is evaluated by the technical implementation of a web-platform, which will serve as a support tool. This platform will serve for planning and support concerns by providing an integrated and explorative analysis in various fields of application. Figure 3 illustrates how the platform is used in these fields of application by various user groups. Within the figure, the use case "factory planning" is addressed as well other use cases, which will be described in future publications.

## 5 Challenges

The integrative approach of the VPI concept facilitates the use of various applications, which can, for example, be deployed whilst a planning process without requiring a uniform data format. At the beginning of the use case scenario already described above, different utilization rates of factory capacity are defined. As a consequence, further requirements arise, which concern, for example, the future factory's layout, logistics or stocks. Within the planning process of the factory, data are generated on

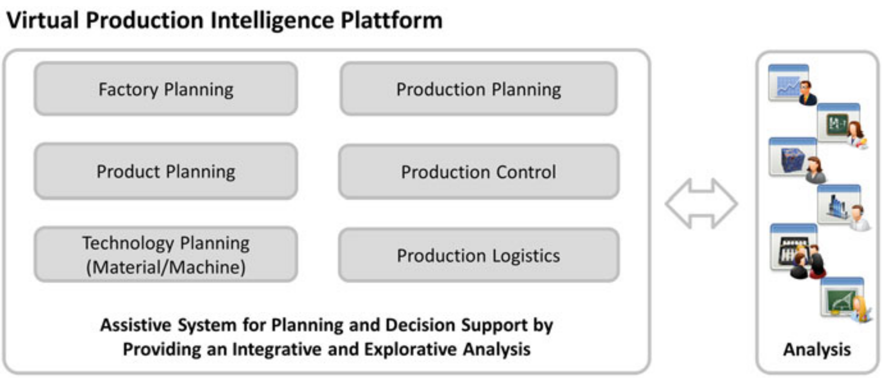


**Fig. 3** The concept of the virtual production intelligence' platform

a large extent. The use of these data depends on the future utilization rates of the factory capacity. In order to analyze the planned processes of the future factory, it is provided that these processes are evaluated beforehand. The planning of these processes will only create an additional value if the identified potentials for optimization are considered in the real process.

Comprehensively, the following questions have to be answered from a planner's point of view:

- Which of the data generated during the process planning are relevant?
- Which key performance indicators are needed with regard to the validation of the considered processes?
- How can the gained knowledge be fed back into the real process?

Regarding the field of information technology, the following questions arise:

- Which data model facilitates the data's analysis?
- Which data analysis methods known from Business Intelligence can serve as role models?
- How to validate the data model's and analysis' functionality appropriately?

Topics that were not considered above will be addressed by the following questions:

- Which simulation model for the considered process is preferred by the user?
- How can the process in consideration be decomposed?
- Which added value may the user expect?

In retrospect, these questions address technical, professional as well as organizational aspects.

## 6 Summary and Outlook

Within this paper, a concept named "Virtual Production Intelligence" (VPI) has been presented, which describes how the solutions developed within the field of "Business Intelligence" can be adapted properly to the one of virtual production. This concept, which is both holistic and integrated, is used for the collaborative planning, monitoring and control of core processes within production and product development in various fields of application.

Furthermore, the technical implementation of this concept was made a subject of discussion in terms of the Virtual Production Intelligence Platform (VPI-Platform). The platform's implementation is particularly based on concepts and methods established in the field of Cloud Computing. Challenges that might occur during the realization of the platform were taken into account with regard to technical, professional and organizational aspects.

A further scenario, which will point out the VPI's flexibility, will be taken from the field of laser cutting. Thereby, the focus will lie on the problem of analyzing a simulated cutting process in such a way that desired characteristics of the concrete cutting process can be realized. The configuration settings for the cutting machine resulting in the desired cutting quality are a part of the analysis outcome. An additional value for the real cutting process arises after feeding back the analysis outcomes into this process.

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# Virtuelle Produktion—Die Virtual Production Intelligence im Einsatz

**Daniel Schilberg, Tobias Meisen und Rudolf Reinhard**

**Zusammenfassung** Die virtuelle Produktion soll einen Beitrag leisten, dass in Hochlohnländern produzierende Industrien weiterhin Konkurrenzfähig sind und sogar Ihren Entwicklungsvorsprung in Hochtechnologien halten und ausbauen können. Um die virtuelle Produktion in diesem Kontext effektiv einsetzen zu können, muss eine Basis geschaffen werden, die eine ganzheitliche, integrative Betrachtung der eingesetzten IT-Werkzeuge im Prozess ermöglicht. Ziel einer solchen Betrachtung soll die Steigerung von Produktqualität, Produktionseffizienz und -leistung sein. In diesem Beitrag wird ein integratives Konzept vorgestellt, das durch die Integration, die Analyse und die Visualisierung von Daten, die entlang simulierter Prozesse innerhalb der Produktionstechnik erzeugt werden, einen Basisbaustein zur Erreichung des Ziels der virtuellen Produktion darstellt. Unter Berücksichtigung der Anwendungsdomäne Produktionstechnik und der eingesetzten kontextsensitiven Informationsanalyse mit der Aufgabe den Erkenntnisgewinn der untersuchten Prozesse zu erhöhen, wird dieses Konzept als Virtual Production Intelligence bezeichnet.

**Schlüsselwörter** Produktionstechnik · Digitale Fabrik · Datenverarbeitung

## 1 Einleitung

Der Markt für industriell gefertigte Güter verändert sich immer schneller, so müssen sich Unternehmen der Herausforderung stellen, das einerseits individuelle Kundenanforderungen stetig zunehmen, der für ein Produkt zu erzielende Preis jedoch, trotz des zusätzlichen Aufwands, nur gering steigt. Dies betrifft insbesondere Unternehmen, die in Hochlohnländern agieren, da der globale Wettbewerb für wenig individualisierte Produkte besonders durch die BRICS (Brasilien, Russland, Indien, China, Südafrika) Staaten dominiert wird [1]. Durch die Individualisierung und Leistungssteigerung von Produkten nimmt jedoch die Komplexität von Produkten und Produktionsprozessen in der maschinellen und automatisierten Fertigung stetig zu.

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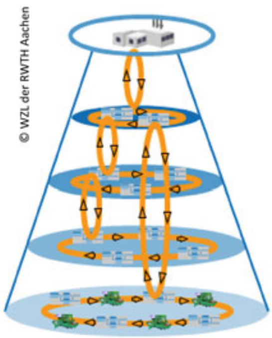
Dies wiederum resultiert in neuen Herausforderungen an die Planung von Produkten und die verbundene Planung der Produktfertigung [2]. Um sich diesen Herausforderungen zu stellen werden Maßnahmen benötigt, die den Anforderungen, die aus der höheren Komplexität resultieren, gerecht werden. Eine Maßnahme, um dieses Problem handhabbar zu gestalten, ist eine intensivere Produktdesign- und Produktfertigungsplanung, die durch den massiven Einsatz von Simulationen und weiteren IT-Werkzeugen die Anwender in die Lage versetzt, die an ein Produkt und deren Fertigung gestellten Anforderungen zu erfüllen. Zur weiteren Verbesserung des Einsatzes der Simulationen und IT-Werkzeuge ist es wichtig diese nicht einzeln zu betrachten sondern in ihrem Einsatzkontextes, d. h. welches Werkzeug wird zu welchem Zweck an welcher Stelle des Planungs- oder Fertigungsprozess eingesetzt. Es muss eruiert werden welche Informationen mit welchem Aufwand zwischen den Werkzeugen ausgetauscht werden. Um eine entsprechende Maßnahme zu formulieren und auszuführen, muss eine Basis geschaffen werden, die eine ganzheitliche, integrative Betrachtung der eingesetzten Werkzeuge im Prozess ermöglicht. Ziel einer solchen Betrachtung soll die Steigerung von Produktqualität, Produktionseffizienz und leistung sein [3].

Aufgrund der rapiden Entwicklung der nutzbaren Rechenleistung von Computern ist der Einsatz von Simulationen in der Produktdesign- und Produktfertigungsplanung schon länger etabliert und die Anwender werden immer weiter in die Lage versetzt Zusammenhänge immer detaillierter virtuell abzubilden. Dies hat einen Wechsel hinsichtlich der Art und Weise verursacht, wie Vorbereitungs- und Planungsaktivitäten in der Produktion durchgeführt werden. Anstelle der frühzeitigen Entwicklung von physisch existierenden Prototypen wird der Betrachtungsgegenstand zunächst als digitales Model entwickelt, das eine Abstraktion der wesentlichen Charakteristika oder Verhaltensweisen der Prototypen repräsentiert. In der anschließenden Simulation wird das digitale Model genutzt, um Aussagen über Verhalten und Eigenschaften der zu untersuchenden Systeme und Prozesse abzuleiten. Dieser Einsatz von digitalen Modellen in der Produktion wird durch den Begriff der virtuellen Produktion beschrieben, die eine „durchgängige, experimentierfähige Planung, Evaluation und Steuerung von Produktionsprozessen und anlagen mit Hilfe digitaler Modelle" [4, 5] bezeichnet.

In diesem Beitrag wird ein integratives Konzept vorgestellt, das durch die Integration, die Analyse und die Visualisierung von Daten, die entlang simulierter Prozesse innerhalb der Produktionstechnik erzeugt werden, einen Basisbaustein zur Erreichung des Ziels der virtuellen Produktion darstellt. Unter Berücksichtigung der Anwendungsdomäne Produktionstechnik und der eingesetzten kontextsensitiven Informationsanalyse mit dem Ziel den Erkenntnisgewinn der untersuchten Prozesse zu erhöhen, wird dieses Konzept als Virtual Production Intelligence bezeichnet. Zur Illustration dieses Ansatzes wird zunächst die Problemstellung genauer spezifiziert, danach wird die Vision der Digitalen Fabrik aufgespannt, um mit diesen Kenntnissen ein tieferes Verständnis für die Problematik von Heterogenität von IT-Werkzeugen zu schaffen. Ziel des Beitrags ist die Darstellung wie die Virtual Production Intelligence zur Überwindung der adressierten Herausforderungen beiträgt.

**Informationsfluss in einem produzierendem Unternehmen**




| Ebene | IT-Werkzeug |
|---|---|
| Management | Enterprise Ressource Planning System |
| Betriebsleitebene | Manufacturing Execution System |
| Prozessleitebene | Supervisory Control and Data Acquisition |
| Steuerungsebene | Speicherprogrammierbare Steuerung |
| Feldebene | Protokolle |

Schwierigkeiten
- Datenaustausch zwischen den einzelnen Ebenen.
- Ganzheitliche Abbildung von Produktions- und Fertigungsverfahren.

**Abb. 1** Automatisierungspyramide [6]

## 2 Problemstellung

Als Kernproblem der virtuellen Produktion kann die heterogene IT-Landschaft in produzierenden Unternehmen identifiziert werden. Es werden wie in der Einleitung dargestellt unterschiedlichste Softwarewerkzeuge zur Unterstützung verschiedenster Prozesse eingesetzt, wobei Daten und Informationen nicht ohne großen Aufwand zwischen den Softwarewerkzeugen ausgetauscht werden können. Die Automatisierungspyramide bietet eine gute Möglichkeit diese Problematik genauer zu beschreiben. In Abb. 1 sind die Ebenen der Automatisierungspyramide mit den für die Ebene korrespondierenden eingesetzten IT-Werkzeugen sowie der Informationsfluss zwischen den Ebenen dargestellt. Hierdurch wird deutlich, dass es auf jeder Ebene Werkzeuge gibt, die die jeweiligen Prozesse unterstützen. So werden auf der obersten Ebene Steuerungs- und Kontrollentscheidungen für die Unternehmensleitung mit Hilfe von Enterprise Ressource Planning (ERP) Systemen unterstützt. Diese Systeme ermöglichen es den Entscheidern im Management den unternehmensweiten Ressourceneinsatz vom Mitarbeiter über Maschinen bis hin zu Rohstoffen zu überwachen.

Auf den Ebenen darunter sind die Manufacturing Execution Systems (MES), die Betriebsdatenerfassung (Supervisory Control and Data Acquisition SCADA) sowie die Speicherprogrammierbaren Steuerungen (SPS) zu finden und auf der untersten Ebene, der Feldebene, liegt die Datenübertragung auf Basis von entsprechenden Protokollen. Die Softwarewerkzeuge sind auf der jeweiligen Ebene sehr weit entwickelt, um die entsprechenden Prozesse zu unterstützen. Was mit Blick auf die virtuelle Produktion aber nicht realisiert ist, ist das auch vom Verein Deutscher Ingenieure (VDI) adressierte einheitliche Datenmanagement und damit eine Möglichkeit Daten und Informationen über alle Ebenen hinweg verwenden zu können. So ist es in der Regel nur mit sehr großen Aufwänden für Konvertierungen und Aggregieren möglich, die Daten eines SPS über das SCADA und MES bis hinauf zum ERP System zu übertragen, so dass auf Basis von aktuellen Maschinensteuerungsdaten Ressourcenplanungen durchgeführt werden können bzw. sich aus der Ressourcenplanung Steuerungsdaten für die SPS ergeben. Zurzeit gibt es in den meisten Unternehmen nur einen Datenaustausch zwischen einzelnen Ebenen und keinen Informationsfluss über alle Ebenen hinweg. Dadurch ist eine ganzheitliche Abbildung von Produktions- und Fertigungsverfahren nicht möglich [7].

Zurzeit ist ein durchgängiger Informationsfluss nur bei dem Einsatz von maßgeschneiderten Architekturen und Adaptern vorhanden, um die Problematik der Heterogenität zu überwinden. Dies ist mit hohen Kosten verbunden, daher liegt meist bei kleinen und mittleren Unternehmen (KMU) keine Integration aller vorhandenen Daten in ein System vor. Es existiert eine hohe Anzahl unterschiedlicher IT-Werkzeuge für die virtuelle Produktion. Diese ermöglichen die Simulation verschiedenster Prozesse, wie etwa in der Fertigungstechnik die realitätsnahe Simulation von Wärmebehandlungs- und Walzverfahren oder die digitale Betrachtung komplexer Maschinen wie Laserschneidmaschinen. Hierbei haben sich unabhängig voneinander unterschiedliche Datenformate und -strukturen zur Darstellung der digitalen Modelle entwickelt. Während hierdurch die unabhängige Simulation einzelner Aspekte der Produkt- und Produktionsplanung durch einzelne Simulationen möglich ist, ist die integrative Simulation komplexer Produktionsprozesse nicht ohne hohe Kosten- und Zeitaufwand möglich, da in der Regel keine Interoperabilität zwischen den heterogenen IT-Werkzeugen entlang der Automatisierungspyramide gegeben ist.

Ein Lösungsansatz zur Überwindung der Heterogenität ist die Homogenisierung durch die Definition eines einheitlichen Datenstandards, hierdurch ist die Überführung der heterogenen Datenformate in diesen Standard durch den Einsatz von den zuvor erwähnten spezifischen Adaptern möglich. Dieser Lösungsansatz ist für das betrachtete Szenario jedoch aus zwei Gründen nicht praktikabel. Zum einen führt die Vielfalt möglicher IT-Werkzeuge, die eingesetzt werden, zu einem komplexen Datenstandard, wodurch dessen Verständnis, Pflege und Nutzung zeit- und kostenintensiv wird. Zum andren sind Probleme der Kompatibilität zu einzelnen Versionen des Standards zu adressieren (siehe STEP (DIN EN ISO 10303)). So muss der Standard zu älteren Versionen kompatibel sein und ständig weiterentwickelt werden, um aktuelle Entwicklungen von IT-Werkzeugen zu berücksichtigen und der fortschreitenden Weiterentwicklung durch Forschung zu entsprechen [8, 9].

Ein anderer Ansatz, der in dem vorliegenden Beitrag als Basis gewählt wird, beinhaltet die Nutzung von Konzepten der Daten- und Anwendungsintegration, bei denen die Definition eines einheitlichen Standards nicht erforderlich ist. Damit kein Standarddatenformat notwendig ist, muss die Interoperabilität der IT-Anwendungen auf eine andere Art und Weise gewährleistet werden. Dies geschieht durch die Abbildung der Aspekte der verschiedenen Datenformate und -strukturen auf ein sogenanntes integriertes Datenmodell oder kanonisches Datenmodell [9, 10]. In aktuellen Ansätzen werden diese Konzepte, um den Einsatz semantischer Technologien erweitert. Die semantischen Technologien ermöglichen ein kontextsensitives Verhalten des Integrationssystems. Die Fortführung dieses Ansatzes ermöglicht die sogenannte adaptive Anwendungs- und Datenintegration [11, 12].

Die Integration aller im Prozess erfassten Daten in eine konsolidierte Datenhaltung ist aber nur der erste Schritt zur Lösung der Problemstellung. Die größere Herausforderung, die es zu überwinden gilt, ist die weitere Verarbeitung der integrierten Daten entlang eines Produktionsprozesses, um eine Verknüpfung der IT-Werkzeuge über alle Ebenen der Automatisierungspyramide zu erreichen. Die Fragestellung der Analyse von Daten aus heterogenen Quellen wird seit einiger Zeit bei der Analyse von Unternehmensdaten angegangen. Die Anwendungen, die eine Integration und Analyse der Daten ermöglichen, werden unter der Bezeichnung „Business Intelligence" (BI) zusammengefasst. Den BI Anwendungen ist gemein, dass sie die Identifikation und das Sammeln von Daten, die in Unternehmensprozessen aufkommen, sowie deren Extraktion und Analyse, bereitstellen [13, 14]. Das Problem bei der Anwendung der BI auf die virtuelle Produktion ist, dass die Umsetzung der BI die Herausforderungen der Integration von heterogenen Daten- und Informationsquellen in erster Linie konzeptionell löst und dies bei der Implementierung funktionsfähiger Systeme erhebliche Probleme verursacht. So wird im Konzept bspw. eine Übersetzung der Daten in ein einheitliches Datenformat und die kontextsensitive Annotation vorgesehen, aber eine Übersetzung kann evtl. nicht erreicht werden, da es sich um proprietäre Daten handelt und für die Annotation die Bedeutung nicht bekannt ist. Dies ist auch der Grund warum so viele BI Integrationen bisher fehlgeschlagen sind [15].

Im Folgenden wird dargestellt, dass mit der Vision der Digitalen Fabrik die zuvor adressierten Probleme gelöst werden sollen. Da die Vision jedoch noch nicht realisiert ist wird in den Kapiteln Heterogenität von Simulationen und Lösungsansatz: Virtual Production Intelligence darauf eingegangen wie die nächsten Schritte zur Digitalen Fabrik realisiert werden können. Der Begriff „Virtual Production Intelligence" wurde in Anlehnung an den in der Problemstellung eingeführten Begriff „Business Intelligence" gewählt, der Anfang bis Mitte der 1990er Jahre populär geworden ist. Dabei bezeichnet „Business Intelligence" Verfahren und Prozesse zur systematischen Analyse (Sammlung, Auswertung und Darstellung) von Daten eines Unternehmens in elektronischer Form. Sie verfolgt das Ziel, auf Basis der gewonnenen Erkenntnisse bessere operative oder strategische Entscheidungen in Hinsicht auf die Unternehmensziele zu treffen. „Intelligence" bezieht sich in diesem Kontext nicht auf Intelligenz im Sinne einer kognitiven Größe, sondern beschreibt die Erkenntnisse, die durch das Sammeln und Aufbereiten von Informationen gewonnenen werden. Dies entspricht der Verwendung des Wortes „Intelligence", wie es auch im Kontext für geheimdienstliche Tätigkeiten in der englischen Sprache Verwendung findet (bspw. Central Intelligence Agency - CIA).

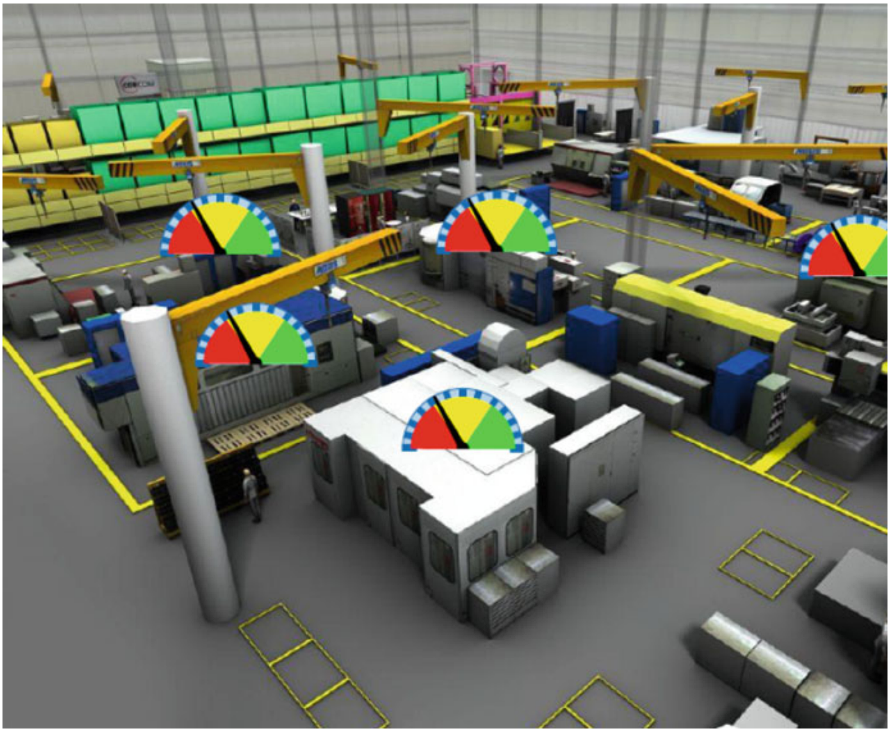


**Abb. 2** Digitale Fabrik mit Indikatoren die anzeigen ob ein Prozess läuft ©WZL der RWTH Aachen & IMA der RWTH Aachen

## 3 Digitale Fabrik

Die Digitale Fabrik (Abb. 2) wird durch den VDI Arbeitskreis in der VDI-Richtlinie definiert [4] als

> der Oberbegriff für ein umfassendes Netzwerk von digitalen Modellen und Methoden, u. a. der Simulation und 3D-Visualisierung. Ihr Zweck ist die ganzheitliche Planung, Realisierung, Steuerung und laufende Verbesserung aller wesentlichen Fabrikprozesse und -ressourcen in Verbindung mit dem Produkt.

Gemäß der VDI-Richtlinie 4499 umfasst das Konzept der Digitalen Fabrik nicht einzelne Aspekte der Planung oder Produktion sondern den gesamten Produktlebenszyklus (Abb. 3). Es sollen alle Prozesse von der Entstehung über den Einsatz bis hin zur Außerdienststellung modelliert werden. Das heißt, die Betrachtung startet bei der Erhebung der Anforderung am Markt, die Entwurfsphasen inkl. aller notwendigen Dokumente, das Projektmanagement, Prototypen (digitale Mockups), die notwendigen internen und externen logistischen Prozesse, die Planung der Montage und Fertigung, die Planung der entsprechenden Fertigungsanlagen, die Montage und Inbetriebnahme der Fertigungsanlagen, das Anlaufmanagement (Ramp Up), die Serienproduktion, der Vertrieb bis zur Wartung und das Recycling bzw. Entsorgung

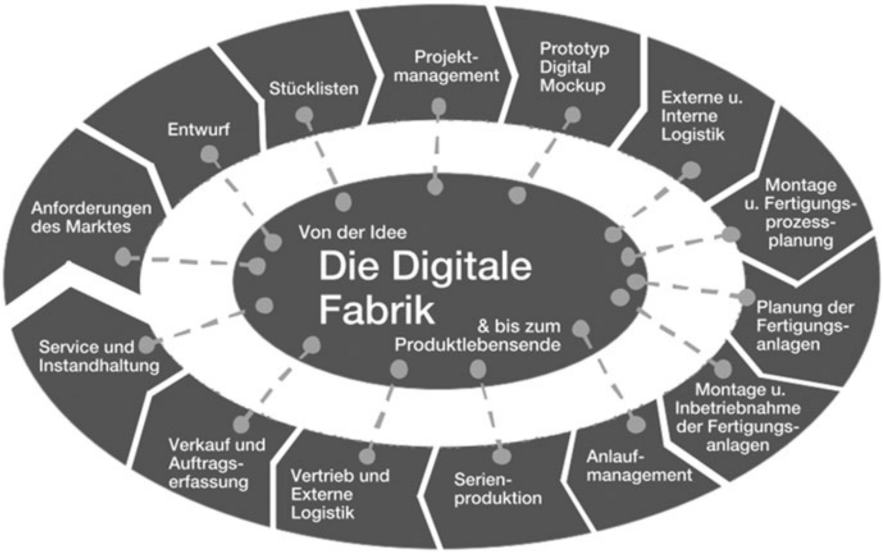



**Abb. 3** Produktlebenszyklus (VDI Richtlinie 4499) [4]

des Produkts sind damit Teil der Digitalen Fabrik. Zurzeit existiert keine Plattform, die dieser Integrationsaufgabe gerecht wird. Es sind aber schon einige Elemente der Digitalen Fabrik auf unterschiedlichsten Ebenen der Automatisierungspyramide oder in Phasen des Produktlebenszyklus realisiert. So gibt es Produktlebenszyklus Management (PLM) Software, die Unternehmen unterstützt den Produktlebenszyklus zu planen, zu überwachen und in Teilen auch zu steuern. Diese Anwendungen sind jedoch meist Insellösungen und ermöglichen nur die Integration von IT-Werkzeugen, die über die gleichen Schnittstellen zum Datenaustausch verfügen und vom gleichen Hersteller bereitgestellt werden. Die Detailtiefe der Abbildung einzelner Phasen des Produktlebenszyklus erreicht dabei nicht die hohe Ortsauflösung von Spezialanwendungen zur Beschreibung einzelner Phasen des Produktlebenszyklus oder von IT-Werkzeugen die sich auf Teilaspekte einzelner Phasen konzentrieren. Die Empfehlung des VDI, Datenmanagement, und -austausch möglichst homogen zu gestalten, kann daher nur bei Neuentwicklungen berücksichtigt werden. Davon abgesehen existiert bis heute kein Ansatz, wie ein Standard für einen solchen homogenen Datenaustausch umzusetzen ist und wie die angesprochene und wohl bekannten Probleme eines Standardisierungsprozesses verhindert beziehungsweise umgangen werden können. Demnach kann selbst ein Vorhaben, das sich gezielt als Beitrag zur Umsetzung der Vision sieht, nicht zu einer Homogenisierung des Informationsflusses beitragen, da nicht definiert ist, wie ein solcher Zustand auszusehen hat. Dazu kommt, dass es keinen Standard gibt und sich Standardisierungsbemühungen wie bspw. Standard for the Exchange of Product Model Data (STEP) gegen proprietäre Formate behaupten müssen. Hierbei muss berücksichtigt werden, dass die proprietären Formate auch genutzt wurden um das Wissen und Fähigkeiten des Softwareanbieters zu schützen.

Mit Blick auf die Visualisierung der Digitalen Fabrik liegen Werkzeuge der Virtual Reality und Augmented Reality vor, die es den Anwendern ermöglichen 3D-Modelle von Fabrikanlagen mit und ohne Menschen zu realisieren und mit diesen auch zu interagieren und mit Informationen zu annotieren. Es ist jedoch keine Echtzeitsteuerung einer physisch vorhandenen Anlage über eine virtuelle Repräsentation der Anlage möglich, bei der die Daten aus dem Betrieb in der virtuellen Anlage dargestellt und für Analysezwecke weiter verarbeitet werden, da die Laufzeiten einzelner Simulationen die Echtzeitanforderung nicht erfüllen. Mit den vorliegenden Techniken, deren Weiterentwicklungen und Neuentwicklungen soll das Ziel der Digitalen Fabrik erreicht werden.

Die Virtual Production Intelligence dient als Basisbaustein für die Digitale Fabrik. Zur Erreichung dieses Zieles ist es nicht notwendig die gesamt Vision der Digitalen Fabrik zu adressieren sondern es ist vielmehr ausreichend den Bereich der simulationsbasierten virtuellen Produktion zu fokussieren (vgl. Abb. 4). Auch hier wird zur Definition der virtuellen Produktion die VDI-Richtlinie 4499 zitiert:

> Simulativ durchgeführte vernetzte Planung und Steuerung von Produktionsprozessen mit Hilfe digitaler Modelle. Zweck der virtuellen Produktion ist die Optimierung von Produktionssystemen und flexible Anpassung der Prozessgestaltung vor einer prototypischen Realisierung. [4]

Die Produktionsprozesse werden hierbei in einzelne Prozessschritte zerlegt, die durch Simulationen beschrieben werden. Die Simulation der einzelnen Prozessschritte geschieht unter Verwendung moderner Simulationswerkzeuge, mit deren Hilfe sich selbst komplexe Produktionsverfahren präzise abbilden lassen. Ungeachtet der hohen Genauigkeit einzelner Simulationen besteht die zentrale Herausforderung bei der virtuellen Produktion jedoch in der Zusammenfassung der einzelnen Prozessschritte zu einer Wertschöpfungskette.

Die bereits erwähnte Virtual Production Intelligence (VPI) wird entwickelt, um in einem ersten Schritt die Interoperabilität von heterogenen IT-Werkzeugen herzustellen und zwar mit deutlich geringerem Aufwand bei Einsatz der zuvor erwähnten maßgeschneiderten Lösungen. In einem zweiten Schritt werden die integrierten Daten, die konsolidiert vorliegen, analysiert und weiterverarbeitet. Bei der VPI handelt es sich um ein ganzheitliches, integratives Konzept zur Unterstützung der kollaborativen Durchführung von Technologie- und Produktentwicklung und der Fabrik- und Produktionsplanung. mit dem Ziel die frühzeitige Identifikation und Beseitigung von Fehlerquellen in Prozessen zu ermöglichen wodurch Optimierungspotenziale erkannt und nutzbar gemacht werden. Zum besseren Verständnis werden die Begriffe ganzheitlich, integrativ und kollaborativ folgendermaßen eingegrenzt:

- *Ganzheitlich*: Es werden alle Teile der adressierten Prozesse berücksichtigt.
- *Integrativ*: Nutzung und Zusammenführung vorhandener Lösungsansätze.
- *Kollaborativ*: Berücksichtigung aller in den adressierten Prozessen involvierten Rollen und deren Kommunikation untereinander.

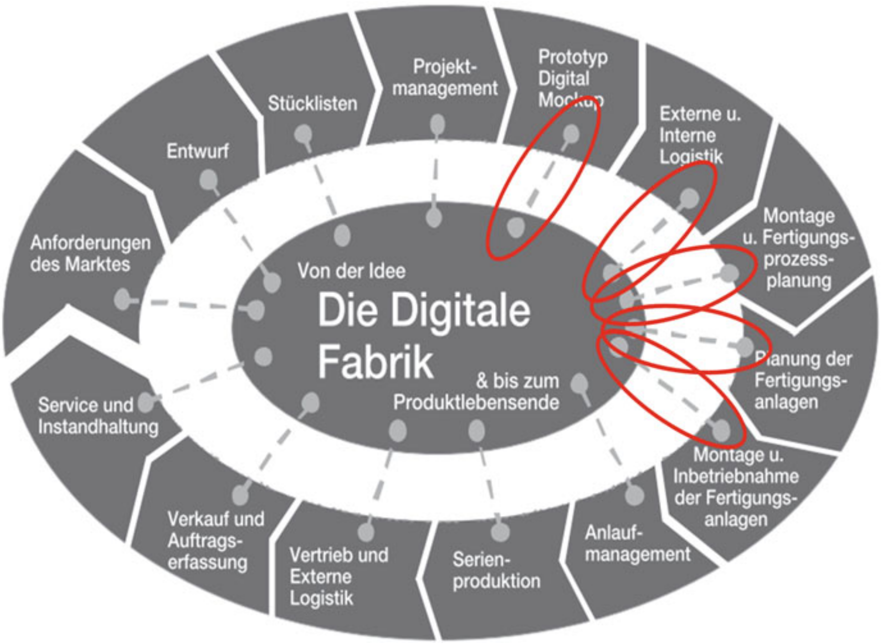



**Abb. 4** Verortung der virtuellen Produktion innerhalb des Produktlebenszyklus nach VDI Richtlinie 4499 [4]

Im nächsten Abschnitt werden die bereits erwähnten Heterogenitäten, die durch den Einsatz der VPI überwunden werden sollen, näher betrachtet.

## 4 Heterogenität von Simulationen

Nach ISO/IEC 2382-01 liegt Interoperabilität zwischen Softwareanwendungen vor, wenn die Fähigkeit zu kommunizieren, Programme auszuführen, oder Übertragung von Daten zwischen verschiedenen Funktionseinheiten in einer Weise ermöglicht wird, ohne dass der Benutzer Informationen über die Eigenschaften der Anwendung hat. Abb. 5 fasst die Heterogenitäten zusammen, die wesentlich dazu beitragen, dass keine Interoperabilität ohne maßgeschneiderte Adapter erreicht wird [16–18].

Mit technischer Heterogenität werden die Unterschiede in der Art und Weise wie auf Daten oder Anwendungen von Benutzern oder weiteren Anwendungen zugegriffen wird bezeichnet. Die syntaktische Heterogenität beschreibt die Unterschiede in der Abbildung von Daten, bspw. unterschiedliche Codierungsstandards wie ASCII oder Binär Codierung, oder die Abbildung von Fließkommazahlen als float oder double und ihre interne Repräsentation. Diese beiden Arten der Heterogenität können relativ einfach durch den Einsatz von Adaptern überwunden werden, jedoch ist hier ein möglichst generisches Konzept zu verfolgen, so dass eine weitere Verwendung

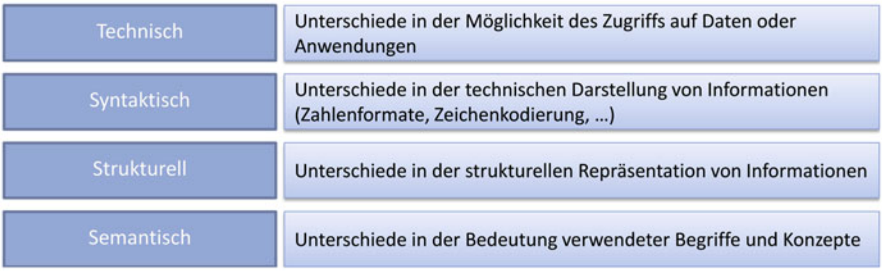



**Abb. 5** Arten der Heterogenität von Simulationen

dieser Adapter ermöglicht wird. Für die technische Heterogenität stehen hierfür eine Vielzahl unterschiedlicher Bibliotheken und Lösungen zur Verfügung. Ebenso verfügen moderne Programmierkonzepte über implizite Typanpassungen und ermöglichen ebenso die kontrollierte explizite Umwandlung von Daten [16–18].

Die Überwindung der strukturellen und der semantischen Heterogenität stellt die ungleich größere Herausforderung dar. Bei der strukturellen Heterogenität werden Unterschiede in der Repräsentation von Informationen adressiert. Semantische Heterogenität beschreibt die Unterschiede in der Bedeutung der domänenspezifischen Entitäten und der für ihre Auszeichnung verwendeten Begriffe. So können zwei Simulationen den Begriff der Umgebungstemperatur verwenden, bei Simulation A wird damit die Hallentemperatur beschrieben in der ein Aufheizofen steht und in Simulation B wird damit die Temperatur im Ofen in unmittelbarer Umgebung des aufzuheizenden Objekts ausgezeichnet. Im Folgenden wird die VPI vorgestellt, die Methoden bereitstellt um diese Arten von Heterogenität zu überwinden und die notwendige Interoperabilität zwischen den Anwendungen zu gewährleisten [16–18].

## 5 Lösungsansatz: Virtual Production Intelligence

Die Analyse der Daten erfolgt mit Hilfe von analytischen Konzepten und IT-Systemen, welche die Daten über das eigene Unternehmen, Mitbewerber oder die Marktentwicklung im Hinblick auf den gewünschten Erkenntnisgewinn auswerten.

Die „Virtual Production Intelligence“ hat das Ziel, die in einem Simulationsprozess entstandenen Daten zu sammeln, zu analysieren und zu visualisieren, um Erkenntnisse zu generieren, die eine ganzheitliche Bewertung der einzelnen Simulationsergebnisse und des aggregierten Simulationsergebnisses ermöglichen. Grundlage der Analyse sind Expertenwissen sowie physikalische und mathematische Modelle. Durch eine immersive Visualisierung werden die Anforderungen an eine „Virtual Production Intelligence“ vollständig abgedeckt.

Die Integration von Ergebnissen eines Simulationsprozesses in ein einheitliches Datenmodell ist der erste Schritt, um Erkenntnisse aus diesen Datenbeständen zu

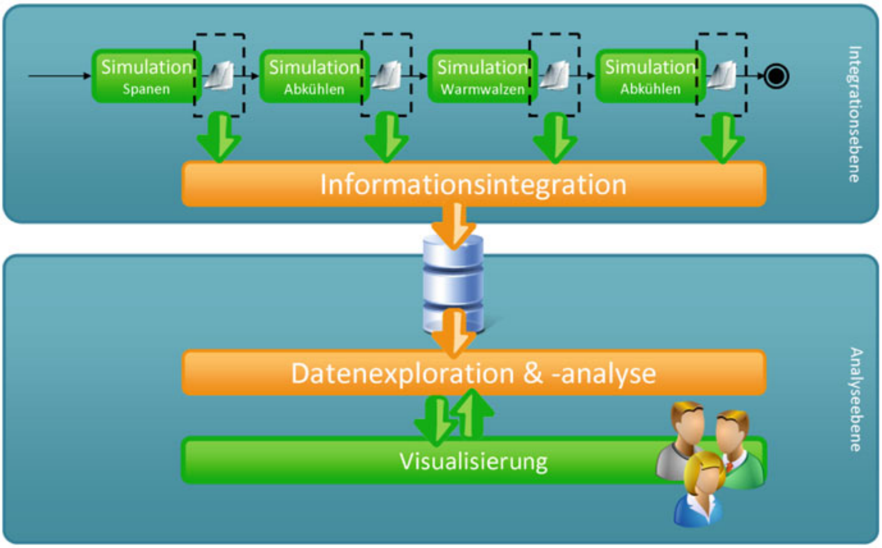



**Abb. 6** Datenexploring und -analyse

gewinnen und die Extraktion von versteckten, validen, nützlichen und handlungsrelevanten Informationen zu realisieren. Diese Informationen umfassen beispielsweise die Qualität der Ergebnisse eines Simulationsprozesses oder in konkreteren Anwendungsfällen auch die Ursachen für die Entstehung von Inkonsistenzen. Zur Identifikation solcher Aspekte stehen dem Analysten zurzeit nur begrenzte Möglichkeiten zur Verfügung. Mit der Realisierung einer Integrationslösung aber wird die Möglichkeit einer einheitlichen Betrachtung aller Daten ermöglicht. Dies umfasst zum einen die Visualisierung des gesamten Simulationsprozesses in einer Visualisierungskomponente, zum anderen die Untersuchung und Analyse der Daten über den gesamten Simulationsprozess. Hierzu können unterschiedliche Explorationsverfahren herangezogen werden.

Der beschriebene Sachverhalt der Datenexploration und -analyse ist in Abb. 6 zusammenfassend dargestellt: Zunächst werden die Daten entlang des Simulationsprozesses in ein kanonische Datenmodell integriert, dass in Form eines relationalen Datenmodells umgesetzt wurde, so dass eine einheitliche und konsolidierte Sicht auf die Daten möglich ist. Anschließend werden die Daten in der Analyseebene durch den Anwender unter Verwendung der Visualisierung analysiert. Dabei wird der Anwender mittels Datenexploration und -analyseverfahren unterstützt, die direkt innerhalb der immersiven Umgebung angesteuert werden können. Durch die Möglichkeit zum Feedback an die Analysekomponente kann der Benutzer gezielt den Explorationsprozess beeinflussen und Parametrisierungen von Analysen zur Laufzeit der Ergebnisdarstellung vornehmen.

Neben der nachträglichen Analyse durch Experten ist es ebenso sinnvoll, eine Überwachung der Daten während des Simulationsprozesses zu realisieren, da eine

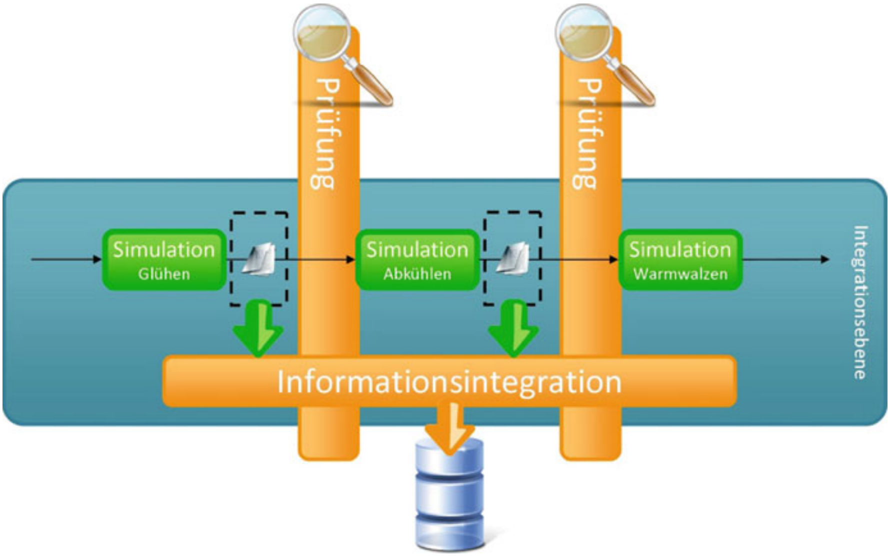



**Abb. 7** Prozessüberwachung als querschnittliche Funktion

solche Prozessüberwachung beispielsweise die Einhaltung von Parameterkorridoren oder anderen Randbedingungen ermöglicht. Würde ein Simulationswerkzeug Parameterwerte außerhalb der definierten Para-meterkorridore liefern, würde dies zu einem Abbruch des Simulationsprozesses führen. Die bisherigen Ergebnisse könnten dann in der Datenanalyse durch Experten analysiert werden, um anschließend eine gezielte Anpassung der Simulationsparameter durchzuführen. Außerdem wäre die Bewertung von Zwischenergebnissen durch Gütefunktionen denkbar, die nach dem Durchlauf und der Integration der Simulationsergebnisse geprüft werden. Ebenso könnte eine Prozess-überwachung die Extraktion von Point-of-Interests (POI) auf Basis von Funktionen ermöglichen, die anschließend in der Visualisierung hervorgehoben werden würden. Der beschriebene Sachverhalt ist in Abb. 7 zusammenfassend dargestellt.

Abbildung 8 zeigt die Komponenten eines Systems zur Realisierung einer „Virtual Production Intelligence". Die Applikationsebene umfasst die Simulationen, die entlang eines definierten Simulationsprozesses aufgerufen werden. Diese sind über eine Middleware miteinander verbunden, die den Datenaustausch realisiert und für die Sicherstellung der Datenintegration und Datenextraktion innerhalb des Simulationsprozesses verantwortlich ist. Dazu wird ein Integrationsserver bereitgestellt, der über einen serviceorientierten Ansatz Dienste zur Integration und Extraktion zur Verfügung stellt. Der Datenbankserver bildet das zentrale Datenmodell ab und dient als zentraler Datenspeicher für alle im Prozess generierten Daten.

Folgendes Beispiel illustriert die Einsatzmöglichkeit der VPI bei der Unterstützung im Fabrikplanungsprozess. Abbildung 9 fasst die Unterstützung in der Fabrikplanung zusammen.

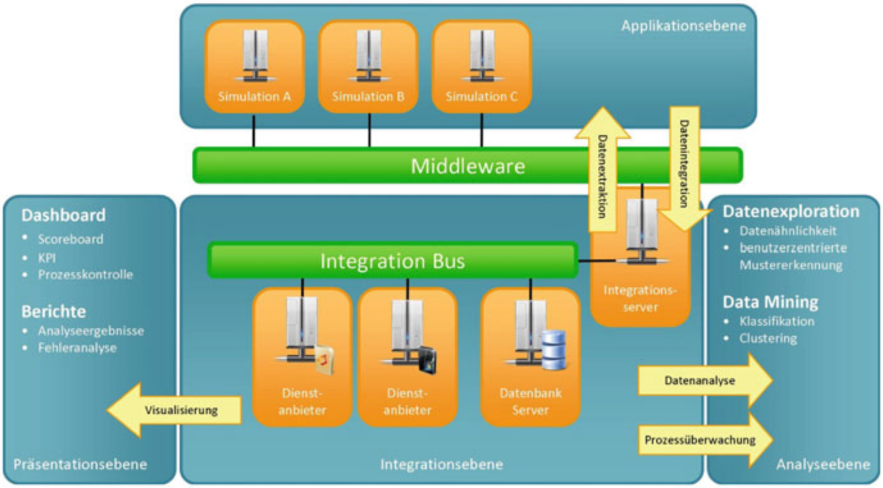



**Abb. 8** Komponenten der Virtual Production Intelligence

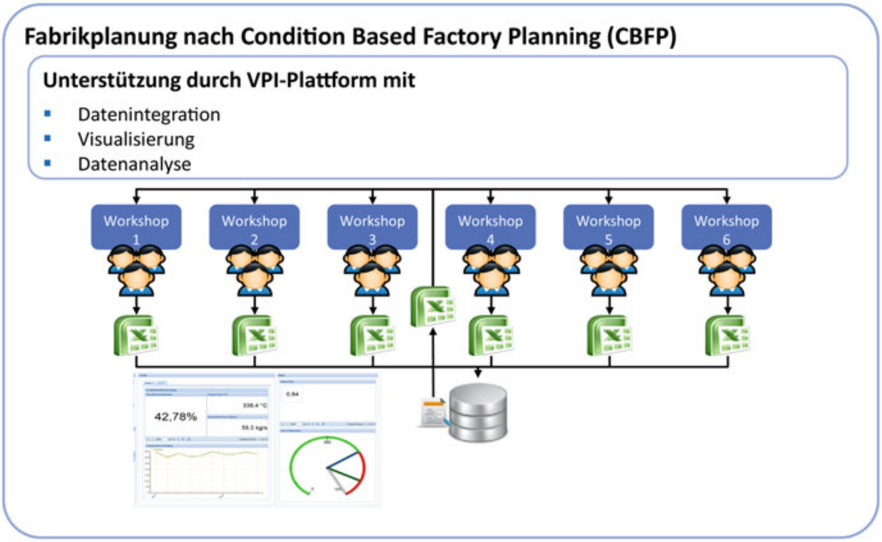



**Abb. 9** Unterstützung in der Fabrikplanung

Die VPI-Plattform wird zur optimierten Fabrikplanung und Prozessketten-Analyse eingesetzt, die Fabrikplanung beruht hierbei auf den Prinzipen des Condition Based Factory Planning (CBFP) [9]. Dieser Ansatz, stellt eine Modularisierung des Planungsprozesses von Fabriken dar, der in Form dezidierter Planungsmodule durchgeführt wird. Die Datenerfassung und Auswertung innerhalb der Planungsphasen erfolgt durch Nutzung gängiger Office-Anwendungen.

Eine Verknüpfung der Planungsmodule untereinander ist daher oft mit einem hohen Übertragungsaufwand hinsichtlich der Datenkonsistenz und -durchgängigkeit verbunden. Insbesondere die Realisation eines Fabrikmodells zur variantenreichen Produktion unter Berücksichtigung verschiedener Szenarien ist nicht ohne weiteres durchführbar, da keine konsolidierte Datenlage bzgl. der einzelnen zu verknüpfenden Planungsmodule vorliegt.

Durch die Anwendung des VPI-Konzeptes auf das CBFP werden vielfältige Möglichkeiten für einen innovativen Produktionsplanungsprozess geschaffen, da eine Zusammenfassung der Planungsmodule in ein gemeinsames Informationsmodell ermöglicht wird. Insbesondere lassen sich durch die zentralisierte Verwaltung von Prozessdaten der verschiedenen Simulationsvorgänge neue Möglichkeiten der Analyse und Visualisierung realisieren. Um eine umfassende und kompakte Darstellung der Ergebnisse und Planungsgrößen der verschiedenen Simulationsmodule zu gewährleisten, wurde aufbauend auf dem VPI-Plattformkonzept eine Web-2.0 Modul entwickelt, die dem Benutzer vielfältige Möglichkeiten der Analyse, Interaktion und Optimierung entlang des Fabrikplanungsprozesses ermöglicht. In Form einer Web-Applikation, welche in jedem modernen Browser ausgeführt werden kann, werden die am Planungsprozess beteiligten Personen mit aktuellen Prozessgrößen aus der Datenbasis versorgt. Somit ist eine Synchronisation der in der Web-Applikation abgebildeten Prozesse und Analysen stets gewährleistet. Der Benutzer hat die Möglichkeit, Anfragen an die Datenbasis zu senden, Manipulationen an den Ein- und Ausgangsgrößen der Simulationen und Änderungen an ihrer Darstellung vorzunehmen. Es wird ermöglicht eine umfassende Prozessketten-Analyse durchzuführen, die insbesondere die Abhängigkeiten mit der Kapazitätsplanung sowie Produktionsstrukturplanung berücksichtigt. Eine wirksame Optimierung verschiedener Produktionsstrukturen, wie etwa die Festlegung der Anzahl der Prozessketten und Produktionssegmente wird erst durch Abbildung der Interdependenzen verschiedener Planungsmodule ermöglicht.

## 6 Zusammenfassung

Mit der VPI wird ein wesentlicher Beitrag zur Realisierung der Vision der Digitalen Fabrik erreicht. Die VPI ist zum einen eine Integrationsplattform, die es ermöglicht heterogene IT-Werkzeuge im Bereich der Produkt- und Produktionsplanung mit einander zu verknüpfen und zum anderen ein auf dem englischen „Intelligence"-Begriff basierendes Analyse Werkzeug, um Wirkzusammenhänge zu identifizieren und zu bewerten. Da die virtuelle Produktion mit der Produkt- und Produktionsplanung Kernbereich der Digitalen Fabrik ist, wurde im Rahmen des Beitrags auf diesen Teil fokussiert. Basis für die VPI ist die Etablierung von Interoperabilität, Die Funktionsweise der VPI wird dargestellt und mithilfe des Beispiels der Fabrikplanung verdeutlicht. Der Einsatz der VPI ermöglicht eine deutliche Aufwandsreduzierung im Engineering zur Erstellung Maßgeschneiderter Integrations- und Analysewerkzeugen, da mit der VPI eine adaptive Lösung vorliegt. Es ist nun möglich mit einer prozessorientierten und damit kontextsensitiven Informationsverarbeitung zu beginnen. Informationen liegen jetzt nicht nur bezogen auf einen einzelnen Prozessschritt vor, in dessen Zusammenhang sie entstanden sind, sondern stehen im Bezug zu dem gesamt Prozess, so dass die Bedeutung und die Gültigkeit von Informationen intensiver betrachtet werden kann.

Die zukünftigen Arbeiten im Rahmen der VPI werden im Bereich der interaktiven explorationsbasierten Datenanalyse liegen. Dabei ist zu evaluieren, inwiefern sich die durch Explorationsverfahren extrahierten Informationen bewerten lassen. Außerdem ist zu untersuchen, wie diese Informationen dem Benutzer in einer immersiven Umgebung dargestellt werden können und wie sich Zusammenhänge von Informationen verständlich und nachvollziehbar präsentieren lassen. Hierzu bieten sich unterschiedliche feedbackgestützte Techniken an, in denen Experten über Feedbackschnittstellen der Visualisierung Analyseergebnisse bewerten und optimieren. Die Kommunikation verläuft dabei bidirektional, das heißt der Benutzer gibt dem System über eine Schnittstelle Feedback, das wiederum vom Analysesystem verwendet wird, um die dargestellte Information zu korrigieren oder zu präzisieren. Das System versucht dabei, das Feedback zu interpretieren, um zukünftig unpräzise, fehlerhafte Aussagen zu vermeiden.

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