Christopher M. Schlick
Editor

Industrial Engineering and Ergonomics

Visions, Concepts, Methods and Tools

Festschrift in Honor of
Professor Holger Luczak

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Industrial Engineering and Ergonomics – Visions, Concepts, Methods and Tools

A Festschrift in Honor of Professor Doktor-Ingenieur Holger Luczak

Human work is one of the main driving forces in the development of our society, economy and quality of life. Latest statistics of the International Labour Organization (ILO 2007) show that at present there are approximately 1.1 billion so-termed “economically active individuals” in five continents, who spend on average more than half of their daytime hours working. Due to this sheer number, the potential impact of scientific models, methods and tools for the design of human work is tremendous. The ergonomic approach to designing human work goes beyond purely economic and financial criteria and aims at a simultaneous optimization of human well-being and overall system performance (IEA 2009). The corresponding analysis and synthesis of multiple interactions among humans and technical elements of a work system is admittedly not simple, but allows for the sustainable and – in the truest sense of the word – healthy development of companies and organizations in the private and public sectors. The ergonomic approach promises to cope successfully with the grand future challenge of demographic change and to improve the quality of work in different economic cycles. In addition to the classical sphere of human work in private and public institutions, one must also consider the 5.6 billion individuals in the so-called First, Second and Third Worlds who do not regularly participate in work and business processes. One of the most noble tasks of researchers and practitioners dealing with human work is to improve the conditions and possibilities of gaining initial employment, maintaining it and continuously improving the quality of work performed.

Human work in engineering design, manufacturing and service has undergone a significant change in the last decades in terms of both structure and process. This change is especially evident in manufacturing systems in advanced countries, where the bottleneck of human performance (and workload) in a large part of work systems has moved from energetic effectual and sensorimotor levels to high levels of human information processing. This bottleneck shift is not only due to significant changes in customer demands towards informational products bundled with innovative services, but also to rapid technological progress, which means that predominantly rule-based and skill-based components of human performance are becoming more and more automated. In spite of the rapid diffusion of new technologies in work systems, there are convincing theoretical arguments (DREYFUS 1992, HAREL 2000, BIALEK et al. 2002) that the "ultimate cognitive machine", as a serious alternative to human ingenuity, creativity and proactivity, is not on the horizon – and may never be – and therefore the decisions and actions of the human when planning, monitoring and optimizing complex production processes and the associated product structures are crucial. In particular, a far-reaching and large-scale system optimization that goes beyond assigning degrees of belief and utility values to decision variables and self-adapting the control parameters is not possible without purposeful and goal-directed human intervention. Human decision making and action regulation can be supported by cognitive technical systems which are embedded in ergonomic human-machine interfaces, but the approach should be symbiotic and aimed at "compatibility" (LUCZAK 1998, KARWOWSKI 2005), rather than substitutional. However, it is not only high levels of human information processing that are resistant to automation because they are hard to model and simulate with known scientific methods; the fundamental mechanisms of human sensory and perceptual systems for extracting predictive information from multiple information sources, for estimating and anticipating critical system states, and for resolving "ill-posed" optimization problems on subconscious levels of cognitive control are not well understood. Therefore, the common pragmatic approach of eliciting the implicit knowledge of highly skilled workers and encoding it through formal symbol systems is not likely to yield the intended results and should be substituted by a scientific approach to augmenting human perception, cognition and motor functions in future manufacturing systems.

In addition to these significant changes on the micro-ergonomic level, one also has to consider the dynamic transformation of companies and supply chains on meso- and macro-ergonomic levels. Whilst the dominant share of positions and workplaces in the European Union and North America only a few decades ago were in classic goods production including the associated extractive industry, more and more high-quality jobs have been created in the so-called service sector. In fact, over the past three decades, the service sector has become the largest segment of most industrialized nations' economies (SPORER et al. 2007) and therefore significantly widens the focus of interest of researchers and practitioners dealing with human work. Especially knowledge-based services such as applied research or new product development as well as knowledge-intensive market services such as maintenance of automated plants and machines are developing very fast (AMIL et al. 2007) and demonstrate an urgent need for novel methods of systematic "service engineering" (LUCZAK et al. 2004) including the underlying service customer- and service employee-oriented work system design. However, knowledge-based and knowledge-intensive services are often tightly interwoven with industrial production and systematic service engineering also has to consider the dynamic interdependencies among products and services (LUCZAK 1999). The companies and organizations designing, developing and managing these advanced product-service systems (MEIER et al. 2008) often need a human-centered work organization to anticipate and stimulate customers' demands and to cope with customer-induced complexity in turbulent markets. One must therefore expect the classic hierarchical and matrix models of industrial management to be more and more substituted by network models of cooperating skilled individuals in multidisciplinary teams, who autonomously coordinate access to shared resources (MALONE 2004). In other words, the old "mechanistic" management methods neglecting multiple external and internal interactions are not expressive enough anymore in the age of value networks (ALLEE 2003). Instead, novel methods and techniques for designing, configuring, and developing open and dynamic socio-technical systems with a large number of individuals who make partially autonomous decisions but also strongly interact in multiply-connected networks have to be invented. Following the holistic approach of LUZCAK et al. (1996), the novel methods and techniques must guide simultaneous systematic interventions for personnel development, organization development and technology development and must be underpinned by proactive project management.

But not only advanced product-service systems and technology-based services are of special interest; the demand for personal services, e.g. in health care, is growing in many countries and suggest that steps need to be taken to reinvigorate classical research in ergonomics concerning stress and strain of service employees and their clients in a dynamically evolving service situation (cf. CARAYON 2007). The superimposition of components of stress and their impact on physical, mental and emotional strain of the involved persons is an especially interesting research subject, which can greatly benefit from the classical works in industrial production (LUCZAK 1979, GFA 2000). In the majority of advanced countries one must expect an accelerated growth in personal services due to the cited demographic change. This is characterized by a rapidly increasing average age in the population as a result of longer life expectancies and lower birth rates. In the United States, for instance, there were approximately 37 million citizens aged 65 and over in 2006, or 12.5 percent of the total population. This number is expected to grow to about 72 million by the year 2030, or 19.3 percent of the total population (US CENSUS BUREAU 2007). Demographic change is also having a big impact in the European Union. The proportion of the working population between the ages of 55 and 64 is expected to increase from 56 million in 2006 (11.4 percent of the total population) to 70 million in 2030 (13.5 percent). Furthermore, the number of people in the European Union aged 65 and older is expected to increase from 82 million in 2006 (16.8 percent) to 122 million in 2030 (23.5 percent) (EC 2006). This societal change is historically unique and will increase the need for novel methods and tools concerning an individualized and age-differentiated design of work systems in engineering design, manufacturing and service to support "healthy aging". These methods and tools are already under development in German priority research programs (FRIELING 2006).

Due to these clear international trends a high-dimensional approach to work system analysis, design and optimization is required. In many interesting application domains the work system (meta-)model will be fairly complex and must not only represent the working persons with their skills, knowledge and abilities, but also the following entities: the team structures and processes, the structure and process organization of the company, the customers and clients, the norms, values, motives, agreements and competencies, the goals, tasks, activities and actions, the work objects, documents and artifacts, the technology, techniques, tools and means for input-output transformation, the formal/informal information and material flows, the chances, risks and possible human errors, the boundary conditions, invariants, state variables, task couplings and fluctuations of the work system as well as the environmental factors. Furthermore, the objective function for work system design and optimization must cover multiple criteria such as customer and client satisfaction, productivity, cost effectiveness, quality, flexibility, energy and resource efficiency, workload, safety, health, self-development, participation etc., which are partially conflicting. One cannot deny that such a high-dimensional and multi-criteria approach is quite challenging for *Arbeitswissenschaftler* in engineering faculties (industrial engineers and ergonomists), as profound knowledge and excellent skills in the classical disciplines – anthropometrics, biomechanics, physiology, control theory, information theory, environmental ergonomics, to name just a few – are still necessary but no longer sufficient. In order to be qualified and competent, the industrial engineer and ergonomist has to consider a vast array of additional sources of scientific (and practical) knowledge in new neighboring disciplines such as cognitive science (LUGER 1994), or even contribute to building up the new community of service science (SPORER et al. 2007), in order to study so-termed interactive work in dedicated research programs in detail. In fact, a work organization with multi-functional and closely interacting teams also increases the frequency and intensity of cooperation between (distributed) working persons and therefore models and methods of communication sciences or social software engineering must also be taken into account. The perfect industrial engineer and ergonomist must consequently be a true modern Gottfried Wilhelm Leibniz, who is widely considered to have been the last universal genius and whose contributions are scattered in numerous scientific journals and in tens of thousands of letters and unpublished manuscripts. Although a second Leibniz has not come of age in industrial engineering and ergonomics so far, there is a small but fine group of outstanding persons in the scientific community who have been able to deliver important contributions to an impressively large variety of classical and novel areas over many decades and therefore come quite close to the Leibnizian ideal.

One of these outstanding persons is Professor Doktor-Ingenieur Holger Luczak. According to his colleagues and friends, he is a man with a brilliant mind, broad and deep knowledge, great communication skills and a person of highest integrity. According to his students, he is a gifted university teacher and a critical, but friendly and open supervisor. Furthermore, he is a man of extraordinary creativity and productivity who has authored and co-authored more than 95 scientific articles in peer-reviewed international and national journals as well as more than 140 peer-reviewed conference proceedings. His publications cover an impressively wide array of scientific subjects such as workload measurement/analysis/assessment, stress and strain, superimposition of stressor variables, analysis and prediction of recovery times for informational-mental and energetic effectual work, ergonomic design and evaluation of human-machine systems and human-computer interfaces, ergonomics of electronic information displays, cognitive engineering, task analysis and modeling, design and evaluation of group and team work, computer-supported cooperative work, production planning and control, service engineering and management, logistics and information management as well as the especially exciting and rarely considered scientific subject of ergonomics and ethics. Selected research lines of Professor Luczak are analyzed in detail in the next section.[1] Professor Luczak has authored, co-authored and edited an almost unbelievable total of 91 books. Among these books are bestsellers such as the first and second editions of the standard German textbook on industrial engineering and ergonomics (*Arbeitswissenschaft* [151, 268a]) as well as the corresponding handbook (*Handbuch Arbeitswissenschaft* [238]), which are frequently used by scientists and engineers all over Germany, Austria and Switzerland. He has also authored and co-authored the equally impressive total of 191 book chapters. His "classic" book chapters were published in the *Handbook of Human Factors and Ergonomics* [365, 555], the *Handbook of Human-Computer Interaction* [219], the *Human-Computer Interaction Handbook* [446, 573] and the *International Encyclopedia of Ergonomics and Human Factors* [552, 553, 554].

The scientist – career path, research lines and research approach

One cannot completely understand the collective works of an ingenious scientist and gifted university teacher without shedding some light on his curriculum vitae and scientific career. Holger Luczak was born on 30 November 1943 in the city of Leipzig, Germany. World War II was raging and many major German cities were under heavy attack by allied air forces. On 4 December 1943 Leipzig suffered its most severe air raids and the baby Holger Luczak was badly wounded. This incident had a lifelong effect on his health and left a characteristic mark on his face. It may also have shaped his peaceful, even pacifist attitude. His family later moved to the western part of Germany where he grew up in a small Westphalian village in a rural community atmosphere, though with severe restraints after World War II. He gained his *Abitur* (German university entrance qualification) at the

[1] The interested reader can find a complete list of Professor Luczak's publications in the publications section. To simplify citation, only the chronological identification numbers of his publications are hereafter given in parentheses.

Paulinum/Schillergymnasium in Münster, which were Latin grammar schools following the ideal of a humanistic education. In 1963, he began his dual studies in mechanical and industrial engineering at Darmstadt University of Technology, Germany. He received the internationally respected German *Diplom-Ingenieur* degree (master's degree) in 1969. From 1969 to 1974, he was a research assistant at the Institute of Ergonomics at Darmstadt University of Technology, where he carried out his doctoral research under the supervision of the famous Professor Walter Rohmert. In 1974, he received his doctorate in engineering. The title of his thesis was "Untersuchung informatorischer Belastung and Beanspruchung des Menschen" (investigation of informational stress and strain on the human [17]). After completing his doctorate, he was appointed assistant professor (*Oberingenieur*) at the same institute and was able to develop his first own research lines. In 1977, he completed his *Habilitation* (the highest academic qualification a person can achieve by their own pursuit in Germany) and was granted the desired venia legendi. His habilitation thesis was titled "Arbeitswissenschaftliche Untersuchungen von maximaler Arbeitsdauer und Erholungszeiten bei informatorisch-mentaler Arbeit nach dem Kanal- und Regler-Mensch-Modell sowie superponierten Belastungen am Beispiel Hitzearbeit" (ergonomic investigations of maximum working and recovery times for informational-mental work on the basis of information-theoretic and control-theoretic models of the human as well as for muscular work with superimposition of heat stress [36]). While in Darmstadt he and his colleagues developed the famous stress-strain concept and later enhanced this important theoretical foundation of ergonomics [17]. The stress-strain concept combines job analysis, stress definition, observation and measurement, with measurement of human strain on the basis of aggregated stressor variables concerning different resources, capacities and abilities. A collection of variables can accordingly be considered as a meaningful entity in terms of the design and evaluation of work processes. At Darmstadt University, Professor Luczak was also involved in several practical research projects in different domains, e.g. air traffic control [29], the postal service [32], the police force [55], and disseminated knowledge into industry [37].

In 1976, he was appointed full professor for Production Technology with a focus on industrial engineering and ergonomics at Bremen University, Germany. Although this was a very important promotion and a highly visible recognition of his academic achievements, it was also an unexpected challenge in terms of severely limited research possibilities. The change from Darmstadt to Bremen was a true jump into cold water. The labs in Bremen were poorly equipped and there was a painful shortage of research funds. He also had to lead a centralized service unit and not an independent research institute, which was rather dysfunctional for natural science-based research. This change from a metaphorical "richly laid table" to a "tabula rasa" had to do with the concept of an *Eckprofessor* (founding professorship), who had to plan and build up a fully equipped engineering faculty with its buildings, labs and services for future colleagues, students and co-workers. In other words, an *Eckprofessor* had to focus on service and not on research in the first years of the faculty. This was not an ideal situation for a young and very ambitious scientist. In spite of these unfavorable conditions, Professor Luczak successfully tracked down research project funds in industry and ministries and founded the renowned Bremen Institute for Industrial Technology and Applied Ergonomics (BIBA) in 1980. Among his research projects was the "Modellversuch Produktionstechnik" (pilot project production engineering [57]) and several humanization projects on "Arbeitsstrukturierung in der Teilefertigung und Montage" (work structuring in manufacturing and assembly) with AEG production units in Northern Germany [50, 68, 71, 80, 100] as well as selected foundries [69, 70]. Moreover, a huge research project with a total budget of more than 9 million German marks was established dealing with the human technology and organizational development of a "ship of the future" [63, 64, 65, 66, 67, 89, 90, 95, 96, 97, 98, 107, 115, 116, 117]. In fact, the focal point of his work shifted from basic research in the lab towards application studies. The industrial context dominated the research goals which focused on concrete demands and effective solutions rather than on theoretical or methodological gaps. However, the adaptation of laboratory and simulation methods to the respective application area guaranteed a science-based system improvement [82, 83, 95]. The shift from the methodological focus in Darmstadt to the forefront of technology in Bremen was coupled to the basic problem of not hindering technological progress through a corrective ergonomics approach, but to anticipate micro- and macro-ergonomics problems in a technology development line and to solve them conceptually [179]. His works in Bremen were complemented by his activities in (co-)authoring a *Denkschrift* [44, 45, 46, 47, 81], some literature surveys and application studies on recovery periods [48, 49, 51, 53], which were complementary to his habilitation thesis. Some theoretical studies regarding the superimposition of stressor variables were also conducted [41, 56]. The famous book *Praktische Arbeitsphysiologie* by G. Lehmann was re-edited by Professor Rohmert and Professor Rutenfranz with the help of Professor Luczak, who contributed no less than five chapters [58, 59, 60, 61, 62].

When the situation in Bremen became uncertain in terms of the development of the Faculty of Production Engineering to its planned full size, Professor Luczak decided to accept a "call" to the Berlin University of Technology in 1982, where the Faculty of Engineering Design and Manufacturing had an open position as head of the Institute of Industrial Engineering and Ergonomics. Following an overlap strategy, the BIBA leadership remained in Professor Luczak's hands for two more years while in parallel he started his first research activities in Berlin. The research lines were adjusted or newly developed in accordance with the focus of the faculty in Berlin. The research line focusing on humanization and human technology of production was pursued [100, 101, 102, 122, 129, 136, 138, 140, 142] and enriched by time scheduling [92, 93, 110, 135] and topics on planning and organization [108, 118, 132, 134]. The research line on disciplinary structures and methods continued to be highly significant [99, 103, 104, 106, 109]. It led to some remarkable surveys [119, 120, 123, 132, 138, 143, 144, 145, 150] and a textbook [151].

Furthermore, a novel research line dealing with engineering design and computer-aided design was established. The focus was on the assessment of stress and strain in engineering design work [91, 94, 111, 112, 121, 125, 126, 127, 128, 130, 133, 137, 139, 149, 153] as well as organizational modeling and simulation. Finally, the new research line of human-computer interaction (or "work with display units", WWDU) was created in addition to the ergonomic design of CAD systems [105, 113, 114, 141]. The research in this area culminated in the hosting of the WWDU 1992 Congress in Berlin, which won international acclaim and was attended by more than 800 participants [147].

In 1992, Professor Holger Luczak was appointed full professor at the famous Faculty of Mechanical Engineering of RWTH Aachen University and became head of the renowned Institute of Industrial Engineering and Ergonomics (IAW – Institut für Arbeitswissenschaft). Simultaneously, he was appointed director of the highly reputed Research Institute for Operations Management (FIR – Forschungsinstitut für Rationalisierung) at RWTH Aachen University and was therefore able to significantly sharpen his profile in industrial engineering and production management. The faculty in Aachen was a fully developed mechanical engineering faculty with more than 45 full professors and one of the best and largest of its kind in the world. It incorporated, for example, chemical engineering and materials engineering in addition to the classic goods production sphere plus advanced application technologies such as textile engineering, automotive engineering, plastics engineering, aerospace engineering etc. His "Institut für Arbeitswissenschaft" already had a good organizational structure with three leading scientists plus research assistants. The university institute was complemented by a federal research institute with three assistant professors and one leading administrator. However, the situation was not comfortable as 60–80% of the research budget had to be brought in through project-oriented research funded by different authorities for basic and applied research (German National Research Foundation DFG, German Federal Ministry of Education and Research BMBF etc.) or directly by industry. Two large institutes with more than 45 research assistants pursuing their doctorates and a corresponding breadth of research areas coupled with financial and leadership responsibility were a suitable challenge for Professor Luczak. The wealth of opportunities and possibilities at RWTH Aachen University also led to an explosion of his publication list from about 150 references before he came to Aachen to about 600 references 13 years later. Because it is not possible to provide a detailed analysis of these publications, only selected contributions are cited below.

When he joined RWTH Aachen University, Professor Luczak restructured the research lines to a certain degree, but their substance was preserved. However, some novelties were introduced. First, the research line in humanization [171] and human technology of production was shifted towards aspects and types of work organization [168, 175, 184], for example so-termed "product islands" [148, 161, 170, 172, 230], "user teams" [152] and other participatory approaches [170, 177, 193, 209, 214, 217, 220, 225, 226, 247]. These topics also required an extensive discussion on human models and design criteria [198, 229, 232, 255, 307, 308, 352, 372, 373, 391, 469] being used for a humanistic organizational development [260, 262, 286, 332, 349, 364, 426, 492]. As the funding for the humanization research program came to an end, this research line ended in 2000 with several surveys [363, 474], but was followed by research on inter-company cooperation [246, 289, 303, 331, 358, 402, 411, 448, 461, 462, 463, 470]. Second, the research line dealing with disciplinary structure was developed further, but with lower intensity: it comprised some renewed surveys carried out on invitation of conference organizers [159, 164, 165, 180, 203, 221, 274] or handbook/encyclopedia editors [205, 210, 234, 238, 239, 240, 241, 242, 279, 296, 309, 328, 365, 369, 432, 521] and also included original works [176, 278, 294, 317, 347, 367, 383, 384, 385, 386, 389, 390, 396, 440, 456, 481, 493, 496]. In recent years, the development of "service engineering" into an academic discipline in its own right, though considerably overlapping with ergonomics, has gained increasing acceptance [314, 321, 424, 433, 441, 482, 489, 494, 508, 514, 520]. Today, there is a lively worldwide debate on service engineering that was initiated and matured to a considerable degree by Professor Luczak and his co-workers. Third, the research line centered around engineering design and computer-aided design was also a continual challenge [162, 178, 183, 188, 189, 199, 207, 219, 250, 256, 298, 324, 333, 345, 380, 522]. However, it was modified and modernized by novel methods of telecooperation in new product development [228, 266, 292, 318, 406, 408, 413, 507] and computer-supported cooperative work in general [247, 257, 262, 306, 326, 353, 366, 403, 425, 430, 442, 459, 479, 488]. Furthermore, a change of the research focus from classical engineering design work to concurrent engineering [222, 251, 267, 277, 293, 319, 404, 428, 447] and chemical process engineering [305, 341, 346, 354, 399, 409, 452, 457, 487] occurred. Fourth, human-computer interaction became a major component of laboratory and empirical research with different focuses. The research covered the complete cycle comprising electronic information displays and human perception [181, 187, 208, 212, 231, 265, 371, 401, 420, 444, 446, 455], central information processing [169, 213, 218, 223, 224, 253, 338, 375, 379, 381, 382, 405, 416, 431, 471, 484, 485, 506, 511] as well as motor processes and input devices [158, 186, 190, 192, 197, 237, 323]. Various application areas were also covered [157, 377, 443, 454, 472, 483, 490, 516, 517, 518, 519]. The wealth of innovations in this field can only be outlined: scientific studies and design solutions for stereoscopic displays in air traffic control [231] and advanced manufacturing systems [224], see-through head-mounted displays for supervisory control of machine tools [265], virtual retinal displays for mobile augmented vision systems [401] etc. A mouse with tactile feedback was also developed [197], the effectiveness of which was proven by experimental variables derived from sensorimotor models. Through the integration of novel displays and input devices into concepts of cognitive engineering, several innovative user interfaces were designed and developed which significantly enhanced human performance [326, 341]. Predictive user models [382] covering the whole range from novice to expert and from the disabled to the proficient worker were a prerequisite of design proposals with a sound theoretical background which were investigated in a hypothesis-driven experimental validation process according to their design gradient. Application areas comprise manual work processes in automotive and aircraft assembly [483], manufacturing with CNC milling machine tools or 3D laser welding cells [213, 223] and also work processes in engineering design and industrial service [305, 341, 409], all backed by the cited novel concepts and techniques. The progress in this still very active research area was substantially influenced by institutes of RWTH Aachen University, especially the ergonomics branch of the Institute of Industrial Engineering and Ergonomics under the leadership of Professor Luczak, as is proven by his clusters of publications. Fifth, a new research line at his institute was the development of concepts for occupational safety and health as well as labor protection according to the new paradigm of health improvement, "good" working conditions as well as individual emotional appreciation of the work situation through positive feelings like the "pleasure of work". These components play a considerable role in new company-wide concepts of *Gesundheitsförderung* (health promotion) [233, 235, 275, 311, 316, 348, 359, 387, 388, 410, 456, 480, 497, 498, 499, 500, 501, 510, 536]. The concept also underpinned the popular approach of "healthy aging" in terms of reducing absenteeism and contributing to the stability and robustness of work and business processes. In fact, occupational safety and health with its ultimate goal of prevention and the introduction of positive design concepts is still a fruitful research domain, where Professor Luczak opened new doors for the growth and prosperity of his institute. One should also not forget the "bread and butter" tasks in ergonomic analysis and design with methodological studies and developments [252], with application-oriented adaptation of methods and measurement techniques [244] and with comparative investigations of design variants [261, 268]. In this context, driving tasks as well as postal video coding [513] came into focus [185, 236, 335, 336, 350, 486], while workplaces at blast cabins required the development of anthropometrical methods [191]. Mobile workplaces found special consideration [468], and the anthropomorphization of tools and technical means were also analyzed [368, 397, 478]. All in all, the demand-driven applied research which is a regular part of most university institutes. However, the work on anthropomorphization attracted the special interest of the scientific community in ergonomics, as it simplifies the transition from rational to emotional design. This is a promising strategy with various future research opportunities.

Concurrently to the research agenda of his university institute, Professor Luczak developed the complementary agenda of the Research Institute for Operations Management. Here, he "inherited" three research groups. The first group dealt with production planning and control (PPC), the second group with logistics, and the third group with "indirect" functions in a company such as maintenance, design etc. The PPC group was restructured according to a trend analysis [154]. The core competencies were extended towards Computer Integrated Manufacturing (CIM) [160] and decision support systems for make-or-buy decisions [173]. The research in advanced planning and scheduling was strengthened [204] and the complexity of CIM put into question [211]. This was the basis for the development of the famous Aachen PPC reference model [269, 270, 271, 282, 287] that includes different types of order processing and respective company types [245], tasks and operations [285] for organizational development [273, 288] and a section for managing software functions and enterprise data [254, 280, 290]. The complete body of knowledge was published in a leading technical textbook [272]. Furthermore, already existing market surveys of PPC software on the basis of more than 1000 differentiation criteria were extended towards Supply Chain Management (SCM) [304] in intercompany cooperation and towards Enterprise Resource Planning (ERP) comprising more organizational units within the company [327, 339]. Here, the organization and management aspects came more and more into focus [356, 376, 417, 437, 466, 467, 502, 512]. Workflow management systems for PPC were studied, too [398]. These studies resulted in a textbook for practitioners [449]. In 2004 and 2005, Professor Luczak handed over the PPC concepts to his FIR successor. They were published in a textbook one year later (SCHUH 2006).

The rationalization approach to indirect company functions was pursued and refined. It was based on time consumption considerations [156, 196] and prognosis of technical and organizational possibilities in foundries [155], in printing industries [262], in after-sales functions of manufacturing industries [276] and especially in synchronization of manufacturing and maintenance [295, 299, 310, 310, 360, 500]. Maintenance Planning Systems were developed following the well-known approach of reliability centered maintenance [419]. However, the logical bridge from indirect company functions to industrial service is rather short. For this reason – partly driven by the Quality Movement [200, 227, 249, 301, 302, 330, 392, 393, 418, 477] – service design, service engineering and service management were incorporated more and more in research and application studies [201, 259, 284, 297, 300, 313, 314, 315, 322, 325, 334, 340, 342, 343, 355, 362, 429, 434, 460, 465, 503, 504, 509, 523]. Later the group was renamed "service management" and drove the development of the cited novel disciplines of "service science" and "service engineering" to a large extent. With this perspective and the generated scientific basis, the transformation from the design and management of classical industrial services – close to engineering concepts – to other types and other aspects (mentality, culture etc.) of service work was carried out successfully.

Research in the logistics group was cultivated via the development of operations research algorithms [202, 281, 414, 464] and via aspects of network organization [215, 216, 258, 263]. Nevertheless, the logistics group came under pressure from two sides. First, the neighboring PPC group incorporated more and more aspects of material and information flows according to MRP I and II concepts into production planning and techniques for the management of procurement, stock and distribution were more and more integrated into ERP and SCM software systems. Second, the "information logistics" approach reshaped the classical works to a large extent and created new competition. In order to cope with these challenges, the group was renamed "Information Management" in 2002 and focused on this aspect of modern companies and company networks. The rapid development of the Internet, in particular, contributed to the development of new and fruitful research areas in Electronic Business [400, 427, 476, 515].

One cannot deny that the *Zeitgeist* and major methodological trends shaped the agenda of the Research Institute for Operations Management to a certain extent. However, Professor Luczak anticipated new and fruitful research areas early and orientated the development of his research lines accordingly. This strategy turned out to be highly successful [489, 493]. Under his leadership and guidance both the Institute of Industrial Engineering and Ergonomics and the Research Institute for Operations Management grew quickly and prospered. When he officially retired in 2005 about 70 research assistants and six assistant professors were employed, making this institution one of the largest and most respected in the world.

In his works throughout the decades Professor Luczak preferred a research approach which his colleagues termed “theory-driven”. In ergonomics, theory-driven means that first a concise research question is defined on the basis of an engineering design problem or a gap of knowledge in the scientific literature. Second, a set of hypotheses concerning the work system under study is formed and a preferably quantitative model of the human, the task, the tools, the work objects and the environmental variables including their interactions is developed. Third, the developed model is checked, simulated, verified and validated so that the experimenter can make precise predictions about stress and strain of the human in the work system, the upper bounds of executability of tasks, the limits of human endurance etc. under different experimental conditions. Fourth, experiments are carried out in the laboratory or in the field and the data are collected through measurements, observations or interviews. Fifth, the data are analyzed and interpreted in order to draw conclusions about the model-based predictions, to cross-validate the model and to verify the previously stated hypotheses (to be precise: the negation of the hypotheses is falsified in the sense of Karl Popper). Sixth, the findings serve as a starting point for forming a new set of hypotheses to be tested in follow-up studies. This approach is demonstrated at its best in Luczak’s classic scientific articles on heart rate variability as a psychophysiological measure of strain [1, 4, 5, 34, 43] and his studies of recovery times for informational-mental work as well as heat work [39, 42, 75]. Especially his control-theoretic models of the cardiovascular and cardiorespiratory system as well as the human thermoregulation system and its coupling with the cardiorespiratory system have set an extraordinary high scientific standard for a younger generation of ergonomists [39a]. Furthermore, he recognized the power of advanced mathematical methods for time series analysis very early on and used them to correlate and fuse large data streams from psychophysiological measurements. Through these works he demonstrated standing in the tradition of the “Max Planck Institut für Arbeitsphysiologie”, a former basic research institute of international renown. For his excellent research contributions and his important services for the scientific community (see below), Professor Luczak received the highest international honors and was appointed Fellow of the International

Ergonomics Association in 2000. One year later he also received the famous Distinguished International Colleague Award of the Human Factors and Ergonomics Society of the United States in recognition of "a non-U.S. citizen who has made outstanding scientific contributions to the human factors and ergonomics field".

The teacher

Professor Luczak's excellence in research is the natural nutrient medium for his excellence in teaching. He developed a unique concept for teaching the fundamentals of industrial engineering and ergonomics including selected application areas. This concept was continuously improved to satisfy the demands of his students. From the very beginning of his academic career in 1969 he had been extensively involved in the preparation and support of lectures and exercises in ergonomics at Darmstadt University of Technology under the supervision of Professor Rohmert. Furthermore, from 1972 to 1976 he was the *Prüfungsassistent* (examination assistant) and had to record every one of his professor's oral examinations in writing. Professor Rohmert held several hundred examinations per year and Professor Luczak therefore had access to a very large empirical base with which to reformulate and restructure the chapters of the lecture notes in continuous cycles. This knowledge about the preconditions, process and outcome of university teaching was very helpful when Professor Luczak was appointed full professor at Bremen University. In Bremen he taught the fundamentals of *Arbeitswissenschaft* in compulsory courses for mechanical and industrial engineers, and variants of advanced methods and tools in elective courses for students of all faculties. He understood teaching as a service for his students that has to be continually improved in accordance with innovation concepts.

When he was in Bremen as member of a faculty of production technology in foundation, he preferred an industry-oriented teaching concept [57] that bound variants of work analysis and work design to clusters of production technologies and company profiles, respectively (SCHWIER 1982). During his time at the Berlin University of Technology, the teaching concept was revised and oriented towards a discipline-structuring approach [79] – in accordance with the possibilities and limitations of a classical faculty of mechanical engineering design and manufacturing. This approach included "methods", "basic knowledge components" in terms of objective working conditions (work forms and work types), "working persons" and "application areas". The catalogue of core elements (*Gegenstandskatalog* [104]) became a widely-known and accepted conceptual framework for teaching purposes. His lecture notes – edited privately and sold on a net cost basis in more than 10,000 copies to students, practitioners and colleagues – became a de facto standard in industrial engineering and ergonomics (LUCZAK 1985–1992). This de facto standard was the basis of the first edition of the cited textbook *Arbeitswissenschaft*, which was published in the renowned engineering textbook series by the Springer publishing house and was sold many thousand times [151]. His scores in student evaluations of lectures were excellent and an impressive demonstration of how a "supplementary" discipline – as it was seen by the majority of his technology-oriented colleagues – can gain recognition and acceptance in an engineering curriculum.

When Professor Luczak joined the huge Faculty of Mechanical Engineering of RWTH Aachen University with more than 1000 students per year in compulsory diploma courses, his teaching concept had to be revised and innovated again to satisfy the new requirements. The lecture structure was therefore developed towards a "problem-oriented" approach. This approach is reflected in the second edition of his *Arbeitswissenschaft* textbook [268a]. Principles of work organization and company-structuring were elaborated and several application examples as well as best practices were included. The paper-based lecture notes were reduced more and more in favor of electronic course material published over the Internet. In the year 2000 the complete body of lectures including all figures, tables and text annotations was made available for free public access. This "courseware" was not only used by students of RWTH Aachen University but also by many foreign students as well as the scientific and practitioners' communities. A special service for students at RWTH Aachen University was to put all written examination questions and tasks on the Internet, so that the standards were made clear. The vision of an "eLearning System in Industrial Engineering and Ergonomics" became reality at RWTH Aachen University in 2003 and later throughout Germany [526, 527, 529, 548]. Furthermore, the Institute of Industrial Engineering and Ergonomics became one of the first teaching units with certified teaching quality according to the EFQM model. The certification process was prepared and evaluated by a doctoral dissertation (KORSMEIER 2002).

Today, the third edition of his standard textbook is in the process of being published. The third edition has been substantially revised by his successor, who took over primary responsibility as both editor and author (SCHLICK, BRUDER, LUCZAK 2009). However, when the "senior scientist" is asked what excellence in teaching means according to his experience and standards, he still has a concise answer [see 564]. Just in numerical terms the facts speak for themselves: more than 10,000 students in compulsory courses, more than 1,000 students in advanced courses, about 100 successful doctoral students and three successful habilitation candidates give an idea of the impact of Professors Luczak's teaching over 30 years as a highly dedicated and innovative university professor. His special way of scientific reasoning as well as his theory-driven approach to the development of concepts, models and methods have thus influenced a significant fraction of university-educated industrial engineers and ergonomists in Germany. Four of his former students have been appointed full professors at international research universities and teach the fundamentals of his school of thought to younger generations of students and practitioners. He regarded teaching as a "service task" involving producers and consumers (quality and co-ordination aspect), technology (media and e-learning) and organization (discipline- and value-oriented), which should be a subject of ergonomical research in itself and must be practiced in never-ending cycles of innovation. There is no doubt that he truly lived this philosophy.

His services for the scientific community

Throughout his academic career Professor Luczak delivered important services for the scientific community. His activities started in 1973, when he was asked to do the preparatory work for an invited speech by Professor Rohmert at the World Congress of the International Ergonomics Association (IEA) in Amsterdam. This was helpful for Luczak as he was thus drawn as scientific co-worker into a group of peers (RUTENFRANZ, LUCZAK, LEHNERT, ROHMERT, SZADKOWSKI 1980), who were preparing a "Denkschrift Arbeitsmedizin und Ergonomie" for the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG). The *Denkschrift* was a natural science-based response to the rather politics-driven "Humanisierung der Arbeit" approach (humanization of work) and stimulated a vivid discussion about the role of social sciences in the discipline and the priorities of paradigms.

In Bremen he held one of only three *Eckprofessuren* (founding professorships) and was responsible for shaping the faculty of production technology at the university. Bremen University was regarded as a kind of antithesis to the classical university model, which had come under significant pressure in the 1968 student revolution. The result of his efforts to involve about 40 leading partners from industry as well as the most progressive professors in production technology into the development of a *Leitbild* was a highly successful model of faculty organization and curriculum development. The novel paradigm left behind the traditional product-oriented boundaries between different sub-disciplines in mechanical engineering and favored a production process-oriented concept for organizational (faculty structure) and personal development (election committees). Today, the Faculty of Production Engineering of Bremen University is one of the most renowned engineering faculties among young scientists in Germany. In Berlin he accepted the task assignment of the "Gesellschaft für Arbeitswissenschaft" (GfA) to overcome the schism between the social- and natural science-based approaches to *Arbeitswissenschaft* in Germany. The result of the project, which was pursued jointly with critical social scientists, became a core definition of the discipline and an ordering model for structuring it [104]. Later he edited the cited *Handbuch der Arbeitswissenschaft* [238]. This handbook provided a place for selected scientific contributions to the discipline and has been supporting peace and harmony between different approaches and paradigms for over 10 years now. It included contributions from approximately 200 German-speaking authors and was the first complete handbook in the German language since the first incomplete attempt by Professor Giese in the 1930s. It can be regarded as a landmark publication. As GfA president, Professor Luczak had to cope in the early 1990s with many aspects of German Reunification. He tried to stabilize the discipline by writing comments and recommendations to the point of exhaustion for scientists and research institutions in the former German Democratic Republic (GDR) that had come under significant political and social pressure in the newly formed Federal Republic of Germany (FRG). An additional challenge was to incorporate excellent and interested researchers and scientists from among the 1300 members of the East German "Gesellschaft für Arbeitshygiene" into the GfA, which had 700 members at the time. This integration process was carried out by mutual consensus and the 1993 president of the GfA was a leading scientist from the former GDR. At the same time Luczak became increasingly involved in IEA affairs (1990-1997). Alongside a position on the IEA council (from the mid 80s until now) he held the "publications chair" and the "science and technology chair" on the IEA executive committee, where he developed the number and structure of Technical Groups/Special Interest Groups to more than two dozen according to the future domains of the discipline. He was also extensively involved in the preparation and structuring of IEA congresses as well as in the formulation of priorities in ergonomics education and curricula in terms of a worldwide quality standard for certification and accreditation bodies (BCPE, CREE etc.). In Aachen he was not only devoted to the cited handbook project but also contributed to GfA memoranda about "Future Research Directions" (2000-2002). He was elected GfA president for a second time in 2003 – an honor that is only very rarely bestowed on a scientist in Germany. He used this demonstration of trust to substantially increase the GfA services for its members and fostered the cooperation between scientific societies dealing with human work in Germany. Some years ago he was admitted to "acatech" and is one of only 282 highly respected members of this German Academy of Science and Engineering. The academy represents Germany in the European Council of Applied Sciences, Technologies and Engineering and in the International Council of Academies of Engineering and Technological Sciences – the global union of academies for technical sciences. He also played an active role on the board of the German Group of University Professors in Work and Enterprise Organization ("Hochschulgruppe für Arbeits- und Betriebsorganization"). At the end of his academic career, Professor Luczak was dean of the Faculty of Mechanical Engineering of RWTH Aachen University for several years. Today, he still chairs the "Club of Professors" of GfA ("Hochschulgruppe Arbeitswissenschaft").

From the very beginning of his career as a university professor he was elected and later reelected several times by his professor colleagues, other scientists and funding authorities as referee/reviewer for the German Research Foundation (DFG). He is elected referee of the Association of Industrial Research Funding (Arbeitsgemeinschaft Industrieller Forschungsvereinigungen, AiF) and was also referee in several governmental research programs of the German Federal Ministry of Education and Research, the Federal Ministry of Economics and Technology, the Federal Ministry of Labor and Social Affairs and various German federal state ministries. For many years he was "curator" (advisory board member) at several research institutes (Fraunhofer and others), faculties and companies. He reviewed the strategic research plans, profiles and works of these institutions and advised on administrative or economical decisions.

Professor Holger Luczak was a longstanding member of numerous editorial boards of peer-reviewed scientific journals (*Ergonomics*, *Applied Ergonomics*, *International Journal of Human-Computer Interaction*, *Theoretical Issues in Ergonomics Science*, *International Journal of Occupational Safety and Ergonomics*, *International Journal of Product Development*, *Zeitschrift für Arbeitswissenschaft* etc.). As GfA president he was responsible for two conferences per year – the Spring Meeting with a scientific focus and around 140 to 450 participants and the Autumn Meeting with application-specific topics relating to companies. Alongside his strong IEA commitment, in his capacity as president of the WWDU Group (Work With Display Units, later Work With Computing Systems WWCS), he organized the Berlin 1992 conference [147] and the Berchtesgaden 2002 conference [407]. Jointly with Professor Zink he organized the ODAM 2003 conference in Aachen [463]. He was an influential and longstanding member of the scientific advisory boards of numerous congresses: HCI, ASEAN Ergonomics, OHS, Production Technology and others. Furthermore, he worked as a referee, reviewer and consultant for scientific establishments and institutions in Austria, Switzerland, Italy, France, Scandinavia, USA, East Asia etc., evaluating research programs, research proposals and restructuring research departments. He also participated in several election committees. The number of reports, manuscripts, CVs, programs, proposals, abstracts, papers and plans that required his qualified comment ran to thousands over the decades. The influential and powerful peer position he held is made clear by the diversity and sheer number of Professor Luczak's commitments and the hard, highly detailed work that justifies the collective "trust". In fact, trust seems to be the dominant success factor in his service to the scientific community: trust in his scientific standing and overview of the discipline, trust in his independent judgment and competent advice, and trust in his management abilities and great leadership.

The Festschrift – structure and contents

There can be no doubt that such an internationally outstanding and influential scientist, teacher and colleague deserves a very special recognition of his lifetime achievements in academia, science and technology. It only remained to find the right opportunity and a dignified framework. Following an old German academic tradition, his colleagues and alumni decided to celebrate Professor Holger Luczak's 65th birthday by gathering and publishing a collection of scientific articles in industrial engineering and ergonomics as well as neighboring disciplines written by a group of internationally recognized researchers. The decision to publish this Festschrift was made during a past GfA Congress and within a few weeks the "critical mass" of committed authors had been reached. In order to present the full spectrum of models, methods and tools in engineering design, production and service, no additional constraints were set on contributions. However, the German academic tradition leaves many degrees of freedom regarding the publication format of a Festschrift and one can find very different approaches – from a loose collection of handwritten articles to printed hardcover books. Knowing that Professor Luczak prefers scientific books and considers other print media to be comparably inferior, the editor decided to aim at the highest honor and to publish this high-quality book. Because of Professor Luczak's excellent reputation the renowned Springer publisher supported this ambitious publication project from the very beginning and deserves special acknowledgement. Special thanks go to Dipl.-Ing. Dipl.-Wirt.Ing. T. Jeske who spent a lot of effort and time getting the festschrift in shape. The result is quite impressive: 93 authors from 12 countries have contributed 46 scientific articles and there were more than 700 book pages to be printed.

The structure of the Festschrift follows the famous ordering model of work processes which was developed by LUCZAK and VOLPERT [104] as a unifying framework for the manifold aspects of the *Arbeitswissenschaft* discipline. The ordering model distinguishes seven structural and six procedural levels resulting when human work is studied by different analytical approaches on different time scales. The hierarchy of levels is shown in Fig. 1.

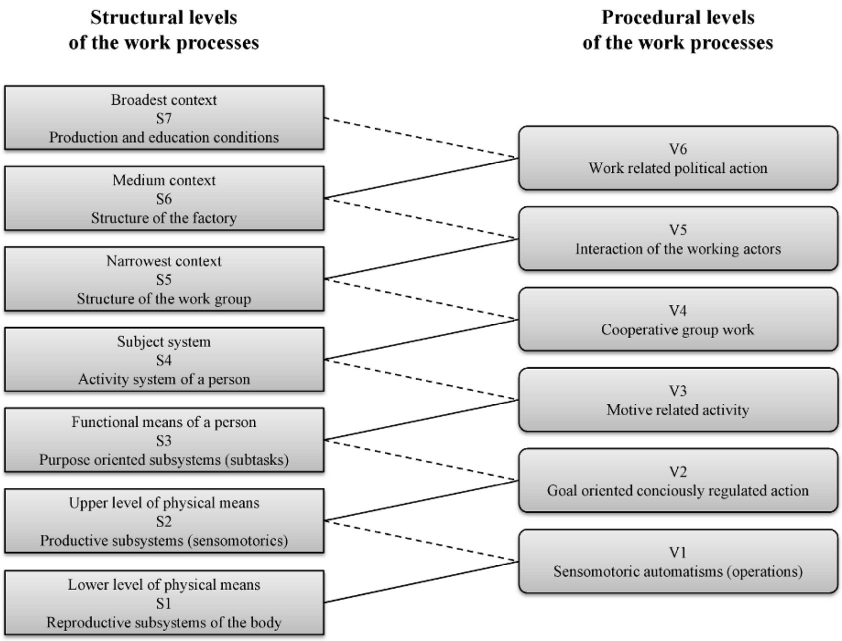

Fig. 1: Structural and procedural levels of work processes [104, 365]

To structure the Festschrift, only the structural levels of the ordering model were considered (Fig. 1, left hand side) and the 46 articles were unambiguously mapped onto one of seven parts. In some cases the clearly broader scope of the article had to be disregarded in favor of providing a clear structure.

On structural level 7 – the highest level of structural abstraction of the ordering model – the societal, social and political aspects of human and work are considered. In accordance with a later minor revision of the ordering model [489], the editor decided to assign contributions dealing with overarching frameworks for industrial sectors, value networks or communities to this level too. The first article on Level 7 and the first in the associated Part 1 of the Festschrift was written by Professor Hans-Jörg Bullinger and his colleague Professor Joachim Warschat. Professor Bullinger is the president of the Fraunhofer Society in Germany and a professor at Stuttgart University. Professor Warschat is a member of the management board of the Fraunhofer Institute for Industrial Engineering (IAO) in Stuttgart. This impulse-giving article is titled “Innovation through New Technologies” and deals with technology development as a driver of innovation in modern companies. Different types of technology development are distinguished and their effects on new products are discussed. Furthermore, four types of innovation are introduced and explained through examples from industry. Finally, typical innovation patterns in organizations are identified.

The second article on level 7 was written by Professor Fritz Klocke and is about “Production Technology in High-Wage Countries – From Ideas of Today to Products of Tomorrow”. Professor Klocke is one of the directors of the Laboratory for Machine Tools and Production Engineering (WZL) and holds the chair of Manufacturing Technology at RWTH Aachen University. Professor Klocke is also head of the Fraunhofer Institute of Production Technology (IPT) in Aachen. In his article, the conceptual foundations and selected research fields of the so-termed Cluster of Excellence on “Integrative Production Technologies for High-Wage Countries” of our Faculty of Mechanical Engineering are presented. This cluster of basic research projects is part of the Excellence Initiative of the German federal and state governments and aims at promoting excellent research in German universities. The article also describes innovative concepts and systems for production planning and integrated production processes.

The third contribution which can be assigned to the seventh level of abstraction was written by Professor Klaus Henning and Andrea Huson. Professor Henning is the head of the Center for Learning and Knowledge Management and holds the chair of Information Management in Mechanical Engineering at RWTH Aachen University, Germany. In their paper with the programmatic title “Innovation Champions – Or How to Achieve (Global) Competitiveness!”, they take a look into the far future by outlining conditions for working, learning and competency development in the year 2020. They argue that there is a need for further research to analyze worldwide trends in these fields and to identify best practices of innovation processes to cope with future challenges.

The fourth article was written by Professor Emerita Gunilla Bradley from the School of Information and Communication Technology of the Royal Institute of Technology (KTH), Stockholm, Sweden. The article is titled "The Convergence Theory and the Good ICT Society – Trends and Visions" and analyzes ongoing social changes related to the rapidly growing use of information and communication technology and its impacts on the structure of work, organizational design, communication processes and work content.

The fifth article was contributed by Professor Michael J. Smith and Professor Pascale Carayon from the United States of America. Professor Smith is a Professor Emeritus of Ergonomics and Industrial Psychology at the Department of Industrial and Systems Engineering of the University of Wisconsin-Madison. Professor Carayon is the Procter & Gamble Bascom Professor in Total Quality and director of the Center for Quality and Productivity Improvement at the same department. Their article is titled "Community Ergonomics and Globalization: A Conceptual Model of Social Awareness" and presents a set of eight so-termed community ergonomics principles in an international and multicultural context. These principles focus on the goals of social responsibility, fairness and social justice, in support of prosperity of an organization or society. With their contribution the authors not only want to honor Professor Luczak, but also the work of Professor Antoinette Derjani-Bayeh (second author), who died in a tragic accident 10 years ago.

"Car Mechatronic" is the title of the sixth article, in which Professor Georg Spöttl presents an approach for designing and developing a new European core occupational profile. Following the objective of educating a broadly and excellently trained as well as customer-oriented technician for future service work in the automotive sector, he describes the structure of a novel curriculum and its development within a European research project. Georg Spöttl is a professor at the University of Bremen and Director of the Institute of Technology and Education (ITB), Germany. His article concludes structural level 7.

Level 6 of the ordering model focuses on the structure of enterprises and companies. Different forms of industrial relations and organization are analyzed as well as managerial decisions which impact on the entire company. The associated Part 2 of the Festschrift starts with an article by Professor Klaus J. Zink and Sven Seibert. They analyze "Performance Measurement from a Macro-Ergonomics Perspective" and give examples of so-called ergonomics performance indicators to be used for an extended corporate performance measurement and management system, which considers the demands of stakeholders both inside and outside the company. Professor Zink holds the chair of Industrial Management and Human Factors (LIA) of the University of Kaiserslautern, Germany, and is head of the Research Institute of Technology and Work (ITA).

The second article, entitled "Technology Management" and written by Professor Dieter Spath, Dr. Karl-Christof Renz, and Klaus Seidenstricker, is closely linked to Professor Bullinger's article. The authors present the foundations of technology management in leading enterprises on different levels of abstraction and how the transition from theory to practice can be successfully achieved. Professor Spath is head of the Institute for Human Factors and Technology Management (IAT) of Stuttgart University and head of the Fraunhofer Institute for Industrial Engineering (IAO). He is the successor of Professor Bullinger in both positions.

This article is followed by a series of three papers contributed by colleagues from our Faculty of Mechanical Engineering of RWTH Aachen University. The first article in the series and third article in Part 2 of the Festschrift deals with quality management in modern companies and was written by Professor Robert Schmitt and Professor Tilo Pfeifer from the Laboratory for Machine Tools and Production Engineering (WZL). Professor Schmitt holds the chair of Metrology and Quality Management at RWTH Aachen University. He is one of the directors of WZL as well as of the Fraunhofer Institute of Production Technology (IPT). Professor Pfeifer is his predecessor and professor emeritus. The article is about "Success with Customer Inspiring Products – Monitoring, Assessment and Design of Perceived Product Quality". The authors introduce the novel concept of the "perceived quality" of a product which is shaped by all the customer's visual, tactile, acoustic and olfactory impressions when using the product and therefore adds subjective perceptible characteristics to the classic concept of product quality.

The fourth article was contributed by Professor Jörg Feldhusen and Frederik Bungert. Professor Feldhusen is head of the Institute for Engineering Design of RWTH Aachen University. The contribution is titled "Pattern Languages to Create a Holistic Methodology for Product Development and to Derive Enterprise-Specific Engineering Guidelines" and gives insights into a novel pattern-based methodology for product lifecycle management.

The fifth article was written by Professor Günther Schuh, Dr. Volker Stich, and Gerhard Gudergan. Professor Schuh is one of the directors of the Laboratory for Machine Tools and Production Engineering (WZL) and holds the chair of Production Engineering at RWTH Aachen University. He is one of the directors of the Fraunhofer Institute of Production Technology (IPT) and director of the Research Institute for Operations Management (FIR). Dr. Volker Stich is the leading administrator of FIR and a former co-worker of Professor Luczak. The article is about "Reference Models – A Basis for Designing Efficient Technical Services" and deals with service management through the embodiment of basic goals. A reference model for technical services is presented and its validity is discussed.

The sixth article dealing with organization at enterprise level is also rooted in the service sector and was written by Priv.-Doz. Dr. Johannes Springer and Karl-Gerhard Freyer. It is titled "Service Modeling and Engineering in the Telematics Industry – The View from the Perspective of a Toll Service Provider". Dr. Springer was a former assistant professor (*Oberingenieur*) at the Institute of Industrial Engineering and Ergonomics of RWTH Aachen University and pursued his doctoral and habilitation studies under the supervision of Professor Luczak. He strongly supported Professor Luczak in developing the ergonomics branch at the institute when he came to Aachen. Nowadays, Dr. Springer is the chief technology officer of Toll Collect GmbH. In his article, the technological foundations of the unique satellite-based tolling service of Toll Collect GmbH are presented and the functions of the major service modules are described. Furthermore, a novel approach to service engineering in terms of tolling systems as a platform for additional value-added services plus the use of third party service platforms for tolling is introduced.

The seventh article on structural level 6 brings human factors issues back into focus and was written by Professor Wolfgang Friesdorf and Dr. Ingo Marsolek. Their article is titled "MedicoErgonomics – A Human Factors Engineering Approach for the Healthcare Sector" and introduces a set of five basic models for the analysis and assessment of direct patient treatment processes. Professor Friesdorf holds the chair of Human Factors Engineering and Product Ergonomics (AWB) at the Berlin University of Technology.

In the eight article, Ernst Koningsveld analyzes "The Impact of Ergonomics" in organizations. He is a senior consultant at TNO Work and Employment, Amsterdam, the Netherlands. In his article, the costs and benefits of ergonomic interventions are studied and examples from the health care sector are given. The paper concludes with a view on the education and training of ergonomists and a note on certification.

Next, Professor Martin Schmauder and Hanka Hoffmann introduce so-called "Effect Chains – A Method for Analysing Qualitative Effects in Occupational Health and Safety at Work" and therefore present an engineering approach to the health management of a company. Professor Schmauder holds the chair of Occupational Science at the Institute for Technical Logistics and Work Science at the Technical University of Dresden, Germany.

An important facet of performance management in modern companies is the design of shift work and shift schedules. This research topic is covered by the tenth contribution, authored by Professor Peter Knauth, Patrick Gauderer, Kathrin Elmerich, and Dorothee Karl. Professor Knauth was head of the Department of Ergonomics at the Institute for Industrial Production of Karlsruhe University, Germany. He has been professor emeritus since 2008. The article describes a "Multi-Perspective IT Evaluation Tool for Shift Schedules" which has been developed and validated on the basis of several basic and applied research projects.

Professor Karlheinz Sonntag and Dr. Alexandra Michel analyze the relationship between ongoing change processes in organizations and occupational health in the eleventh article on "Organizational Change and Occupational Health — Towards a Resource-Based Change Management". Professor Sonntag holds the chair of Work and Industrial Psychology at the Institute of Psychology of Heidelberg University, Germany.

Professor Sebastiano Bagnara and Dr. Roberto Montanari contributed the twelfth and final article on structural level 6 of the ordering model. Professor Bagnara holds the chair of Cognitive Psychology and Ergonomics at the Department of Architecture and Urban Planning of the University of Sassari in Alghero, Italy. Dr. Montanari is at the University of Modena-Reggio Emilia, Department of Engineering Sciences and Methods. The article is titled “Designing Organizational Oblivion” and deals with the rarely considered topic of organizational forgetting and its multiple interactions with the people in the organization, the social community they belong to, the developed physical, organizational and cognitive artifacts as well as the customer, whose needs must be satisfied through the work processes.

On structural level 5 of the ordering model by Luczak and Volpert’s [104] shown in Fig. 1, the cooperation in work groups is considered and human relations are studied. The first article associated with this level in Part 3 of the Festschrift is about goal setting and the effects of goals on the performance of group and team work and was written by Professor Jürgen Wegge, Professor Klaus-Helmut Schmidt and Dr. Julia Hoch. Professor Wegge holds the chair of Work and Organizational Psychology at the Technical University of Dresden, Germany. Professor Schmidt is head of a research group dealing with flexible behavior control at the Leibniz Research Centre for Working Environment and Human Factors (IfADo), Dortmund. The article is titled “Goal Setting: Basic Findings and New Developments at the Team Level” and gives an overview of goal-setting theory, analyzes mediating mechanisms and moderating variables, and describes the latest developments in this research area.

A very different but complementary approach to studying group work is presented in the article by Professor Xiaodong Zhang and Yu Yang from the Mechanical Engineering College of Chongqing University, P.R. China. The article is titled “Simulation of Collaborative Product Development Processes Using Agent-based Modeling” and introduces a human-centered simulation model of engineering design work on the basis of the theory of discrete event systems.

Cooperation development processes are also the subject of research in the article titled “Integrated Modeling of Work Processes and Decisions in Chemical Engineering Design” by Professor Wolfgang Marquardt and Manfred Theißen. The article introduces an ontology of cooperation work processes and design decisions in chemical engineering in conjunction with an integrated approach to system design. Professor Marquardt holds the chair of Process Systems Engineering at our Faculty of Mechanical Engineering of RWTH Aachen University.

The last contribution assigned to level 5 was written by Professor Matthias Jarke, Markus Klann and Professor Wolfgang Prinz. Professor Jarke holds the chair of Computer Science V (Information Systems) of RWTH Aachen University and is head of the Fraunhofer Institute for Applied Information Technology (FIT) in Sankt Augustin, Germany. Under the title “Serious Gaming: The Impact of

Pervasive Gaming in Business and Engineering" innovative concepts and software tools for simulation and training in engineering design and emergency response on the basis of real-time computer games technology are presented and discussed.

On structural level 4, different forms and types of work as well as holistic activities of individual work are analyzed. Four articles constitute this level of abstraction in Part 4 of the Festschrift. The first article was written by Professor Martin G. Helander and Shuan Lo from the School of Mechanical and Aerospace Engineering of Nanyang Technological University, Singapore. The article is about the "Use of Design Equations for Analyzing User Requirements in Process Control". It presents a novel and rigorous approach to modeling and analyzing complex human-system interactions. Although their work aims at the ergonomic design of human-machine systems and would therefore usually be assigned to structural level 3 of the ordering model, their novel framework on design equations for systems analysis (DESA) is unquestionably more abstract than the classic ergonomic techniques and has a wider scope by spanning the goal domain, the functional domain, the physical domain and the action domain. It can thus be considered as a member of a new class of abstract but concise models that must be also considered on level 4 of the taxonomy. The second and third articles on structural level 4 come from the Department of Psychology at the Technical University of Dresden, Germany. Both articles focus on the famous Action Regulation Theory. Professor Winfried Hacker and Dr. Marlen Melzen have written about "Action Regulation Theory: Are the Characteristics of WellDesigned Tasks Valid for Interactive Jobs As Well? – The Concept of Two-dimensional Task Identity in Interactive Work". Professor Hacker is professor emeritus and held the chair of General Psychology. He still heads a research group at this department. In the article an approach is presented to transfering Action Regulation Theory, which was primarily developed for task design and assessment when operating machines and working with computers, to the novel domain of work in the service sector (so-termed interactive work). The article gives empirical evidence from retail tasks concerning the predictive validity of an extended concept of task completeness. The second article, by Professor Peter Richter, Dr. Uwe Debitz and Dr. Andreas Pohlandt, is about "Evaluation of the Quality of Job Design with the Action-Oriented Software Tool REBA – Recent Developments and Applications". The presented software tool is based on a predictive model for strain effects of work-given task characteristics. The authors emphasize that its application is not restricted to the redesign of poorly designed jobs but can also be used as a predictive model for early phases of work system design. Professor Richter is a professor emeritus and the predecessor of Professor Wegge (see first contribution on level 5).

The last paper in Part 4 of the Festschrift deals with creative work forms and is titled "How Can Creativity Be Promoted within the Framework of Vocational Training and further Education?" The article was contributed by Professor Emeritus Uwe Michelsen, who held the chair for Vocational Education and

Training at RWTH Aachen University until 2005. A multi-facetted concept of creativity is introduced and discussed. On the basis of this concept different ways of promoting creativity are presented and explained.

On structural level 3 workplaces and subtasks are considered. This is often the dominant level of abstraction for research in ergonomics at technical universities and also the part of the Festschrift with the most articles. The collection on level 3 starts with a contribution by Professor Matthias Göbel which is titled "Complexity in Ergonomics". Professor Göbel is professor and head of the Department of Human Kinetics and Ergonomics at Rhodes University, South Africa. He is a former research assistant of Professor Luczak and worked at his institute when he was at the Berlin University of Technology. He followed him later from Berlin to RWTH Aachen University, where he finished his doctorate and was a research group leader. In his article, he develops ergonomics extensions to the theory of complex systems and introduces a hierarchically structured recursive approach which sets an excellent frame of reference for the following articles.

The second article is about "Principles, Methods and Examples of Ergonomics Research and Work Design" and was written by Professor Helmut Strasser. Professor Strasser is professor emeritus for Ergonomics at the Faculty of Mechanical Engineering of University of Siegen and past president of the Gesellschaft für Arbeitswissenschaft. He also prefers a systems-oriented perspective of ergonomics that is enriched by examples of work system design in Germany.

The third article comes from the cited "Darmstadt School" of ergonomics. It was written by Professor Ralph Bruder, Holger Radermacher, and Dr. Karlheinz Schaub and presents "Modular Concepts for Integrating Ergonomics into Production Processes". Professor Bruder is director of the Institute of Ergonomics at the Faculty of Mechanical Engineering of Darmstadt University of Technology. In their article a conceptual approach aiming at the continuous and holistic integration of ergonomic issues in different phases of planning processes is developed and validated through a case study that was carried out in the automotive industry.

The fourth article, by Priv.-Doz. Dr. Martin Schütte is about "Methods for Measuring Mental Stress and Strain". Dr. Schütte is a senior scientist at the Leibniz Research Centre for Working Environment and Human Factors (IfADo), Dortmund, and has been GfA secretary since 2003. He was a former research assistant of Professor Luczak at Bremen University. In his article, Dr. Schütte classifies measurement procedures for mental workload and presents a literature survey of engineering and psychological methods for measurement of mental stress. Moreover, he analyzes physiological methods for measuring mental strain as well as subjective methods for recording the subjectively perceived level of mental strain.

The subjectively perceived workload level is also the focus of the fifth article, by Kamiel Vanwonterghem, who is a professor for Ergonomics and Human Ecology. Professor Vanwonterghem is a member of the Faculty of Science of

Rangsit University, Thailand. In his article titled "Ergonomics and Human Factors: Methodological Considerations about Evidence Based Design of Work Systems" he reviews the development of the Subjective Workload Index and presents the results of validation studies over the last ten years in Europe as well as in developing countries.

Professor Shrawan Kumar and Dr. Troy Jones contributed an article titled "Comparison of Ergonomic Risk Assessment Methodology with an Example of a Repetitive Sawmill Board Edger Occupation". Professor Kumar is the co-director of the Physical Medicine Institute and director of research at the University of North Texas, USA. Dr. Jones is at the Faculty of Rehabilitation Medicine of the University of Alberta, Canada. On the basis of a field study in the forest products manufacturing industry, the authors compare the output of five ergonomic risk assessment methods, evaluate their ability to detect differences in risk levels between facilities, and analyze the effect of three posture and two exertion variable definitions on the results of risk assessment.

Safety issues in a different domain are analyzed in the seventh article, titled "Work Science and Aviation Safety" by Professor Emeritus Heinz Bartsch. Professor Bartsch held the chair of Ergonomics and was director of the Institute of Work and Social Sciences of Brandenburg University of Technology. The article analyzes air traffic accidents and presents findings concerning the training of transport pilots. Moreover, a model of human reliability in work systems is presented and human behavior in a "flight work system" is analyzed in the light of the proposed model.

The eighth article was contributed by Professor Vladimir M. Munipov from MIREA University in Moscow, Russia. His article with the title "Development of Theory and Practice in Ergonomics" stands out due to his individual style of writing as well as the numerous references to interactions between his work and the research of the jubilarian. The article gives a detailed overview of the development of ergonomics in the former USSR and in the so-called post-Soviet period and sheds light on many important developments of the discipline in the last decades.

The ninth article is on "Accessibility in Information Technology" and was written by Dr. Ahmet Çakir. Dr. Çakir is the director of the Ergonomic Institute in Berlin, Germany. In his article, he gives an overview of the notion and concepts of "accessibility" and discusses the implication for ergonomics in terms of standardization, the role of standardization bodies as well as legislation in the US and Europe.

The tenth article is a contribution by Professor Spanner-Ulmer and Professor Bubb, focusing on "Ergonomics & Design". Professor Spanner-Ulmer is director of the Institute of Industrial Management and Factory Systems of Chemnitz University of Technology. Professor Bubb holds the chair of Ergonomics and Human Factors at the Faculty of Mechanical Engineering of the Technical University of Munich. Their article reflects on the foundations of ergonomics and design and analyzes automotive exterior as well as interior styling as practical examples. Furthermore, advanced tools for ergonomic product design in automotive engineering such as digital human models are presented and important facets of interculturalism as well as aging are discussed.

The eleventh article was written by Professor Johannsen who has carried out research on human-machine systems for more than 35 years. His article is about the "Design of Visual and Auditory Human-Machine Interfaces with User Participation and Knowledge Support" and gives an overview of this advanced research area including design examples. Professor Johannsen held the chair for Systems Engineering and Human-Machine Systems at the Faculty of Mechanical Engineering of Kassel University. He has been professor emeritus since 2006.

The twelfth article was contributed by his successor, Professor Schmidt. Professor Schmidt is a former research assistant of Professor Luczak and was an assistant professor (*Oberingenieur*) at the Institute of Industrial Engineering and Ergonomics of RWTH Aachen University until 2005. Professor Schmidt has written an article about "Human-Computer Interaction in Aerial Surveillance Tasks" that is centered around a very safety-critical application area of ergonomics knowledge, in which human errors due to minor design flaws can lead to severe accidents or even disasters.

The first author of the thirteenth article is also a former research assistant and research group leader of Professor Luczak. Professor Rötting, Thorsten Zander, Sandra Trösterer and Jeronimo Dzaack analyze "Implicit Interaction in Multimodal Human-Machine Systems". Professor Rötting holds the chair on Human-Machine Systems at the Department of Psychology and Ergonomics of the Berlin University of Technology. The article deals with supporting human-machine interaction through analysis of psychophysiological and behavioral data of the machine user and adapting the structure and contents of the dialogue according to implicitly generated information. In addition, examples on implicit human-machine interaction on the basis of gaze tracking as well as electrophysiological brain activity measurements are presented and discussed. The validity of the latter approach of so-termed passive brain-computer interfaces is analyzed in an experimental study of an interactive game between a human and a computer.

On structural level 2 of the ordering model, the sensorimotor control of tools or working means is represented, and willfully steered organic systems are considered. The first of six articles in Part 6 of the Festschrift that must be assigned to this level is a contribution by the editor of the Festschrift and his co-workers. The article is titled "Design and Evaluation of an Augmented Vision System for Self-Optimizing Assembly Cells". The underlying research is part of the cited Cluster of Excellence "Integrative Production Technologies for High-Wage Countries" at the Faculty of Mechanical Engineering of RWTH Aachen University. The article gives an overview of the role of the human operator in highly automated assembly cells that are embedded in future integrative production systems and presents the results of an ergonomic study of a self-developed enhanced vision system for the supervisory control of cooperating assembly robots.

The second article in this part, contributed by Professor Martina Ziefle, is about the ergonomic assessment of electronic information displays. Professor Ziefle holds the chair of Communication Science at the newly founded Human Technology Center HumTec of RWTH Aachen University. Her article is titled "Visual Ergonomic Issues of LCD Displays – An Insight into Working Conditions and User Characteristics" and analyzes the effects of display anisotropy on visual performance and human errors on the basis of two experimental studies. The first study was conducted with users from different age groups (teenagers, young adults and older adults) and therefore age-related effects concerning information processing speed and accuracy are also analyzed.

The third article deals with temporal factors in human-computer interaction and was contributed by Professor Wolfram Boucsein. Professor Boucsein holds the chair of Physiological Psychology and is head of the Psychophysiological Laboratory at the University of Wuppertal, Germany. He is a founding member of the well-known "Psychophysiology in Ergonomics" (PIE) organization and was its president from 1996 to 2000. The title of his article is "Forty Years of Research on System Response Times – What Did We Learn from It?". In his article he reviews the research on system response times in human-computer interaction up to the late 1960s and presents the main psychophysiological findings concerning the stress-inducing properties of system response times. He also gives an outlook on future research issues in this area that are related to the use of the World Wide Web.

Professor Kurt Landau, Uwe Landau, and Hamed Salmanzadeh contributed the fourth article, entitled "Productivity Improvement with Snap-fit System" to the Festschrift. It begins with an empirical analysis of a class of snap-fits systems being used for efficient automotive assembly. Furthermore, the effects of snap-fit design on the timing of the assembly operations for which a snap-fit attachment is subsequently used are studied. Professor Landau is a professor emeritus of Ergonomics at Darmstadt University of Technology and the predecessor of Professor Bruder. It is interesting to note that Professor Luczak, Professor Landau and Professor Bruder all pursued their doctoral research under the supervision of Professor Rohmert at the Darmstadt University of Technology.

The fifth article is a contribution by Professor Kageyu Noro titled "Developing Seating Designs that Support Traditional Japanese Sitting Postures". Professor Noro is a professor emeritus of Ergonomics at Waseda University, Japan, and founder of ErgoSeating Co. In his article, the traditional Asian way of sitting is analyzed and the theoretical aspects of seating comfort are reviewed. He presents an innovative prototype of a concave chair with a seat pan that replicates the curved shape of the buttocks. In an experimental study this prototype is compared to a chair with a flat seat pan and the results of the comparison are discussed.

Finally, the last two articles are based on theoretical and experimental research which was carried out at the Leibniz Research Centre for Working Environment and Human Factors in Dortmund (IfADo), Germany.

Professor Herbert Heuer is professor for Occupational Psychology and Experimental Psychology at Dortmund University and director of IfADo. His article deals with movements of the fingers-hand-arm system and is titled “Finger Fatigue: Blockings and Approximate Kinematic Invariances”. Professor Heuer analyzes the well-known phenomenon of blockings in repetitive movements and presents findings from his experimental studies of rapid finger tapping. He also examines kinematic alterations due to localized muscle fatigue for rapid oscillations of the index finger in a horizontal plane. His article concludes structural level 2.

The contribution by Professor Andreas Seeber, who headed the research group on neurotoxical effects of hazardous substances at IfADo until his retirement in 2003, is concerned with neurobehavioral effects due to chemical exposures at workplaces. This article belongs to structural level 1 of the ordering model, which deals with autonomous organismic systems and the work environment. In his paper, titled “Neurobehavioral Tests as Evaluation of Neurotoxically Induced Impairments of Health”, Professor Seeber presents the premises and procedures of chemical exposure assessment including the levels of evidence for the neurotoxicity of the chemical under study. He introduces the well-known Symbol Digit Substitution Test and discusses its role in neurobehavioral studies. Furthermore, he compares the test results of five laboratory studies on neurobehavioral effects of human exposure to solvent mixtures being used in the industrial production of paints and discusses the discriminatory power of the test. He presents the results of a meta-analysis of test results for different chemicals such as lead or mercury.

Although level 1 covers a very active and important area of ergonomics research, Professor Seeber’s article is the only contribution on this level and concludes the collection of articles in the Festschrift.

Finally, the editorial of the Festschrift would be incomplete without expressing the deep personal gratitude of the editor to his respected teacher and mentor – to you, dear Holger: Thank you for teaching me industrial engineering and ergonomics with such dedication. Thank you for showing me the beauty of science and the rigor of scientific methods with such patience. Thank you for supervising my academic studies and activities with so much goodwill. And thank you for your friendship and support. I hope we will be able to continue our stimulating scientific discussions for many years to come.

Cui honorem, honorem.

Christopher M. Schlick

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Part 1
Sectors, Value Networks and Communities

1 Innovation Through New Technologies

Hans-Jörg Bullinger, Joachim Warschat

1 Technology Development as a Driver of Innovation

For enterprises today, innovations are the best form of protection against competitors (BULLINGER 2006). The reason is obvious. Innovations make for higher prices and larger market shares because they satisfy customer requirements better than existing products or services, deliver enhanced product quality, or enable the product development time to be accelerated (GÜNTHER & FISCHER 2000, FISCHER 2000 (Fig. 1.1)) – time which can in turn be reinvested. A mere cost reduction, on the other hand, only permits the price range to be lowered.

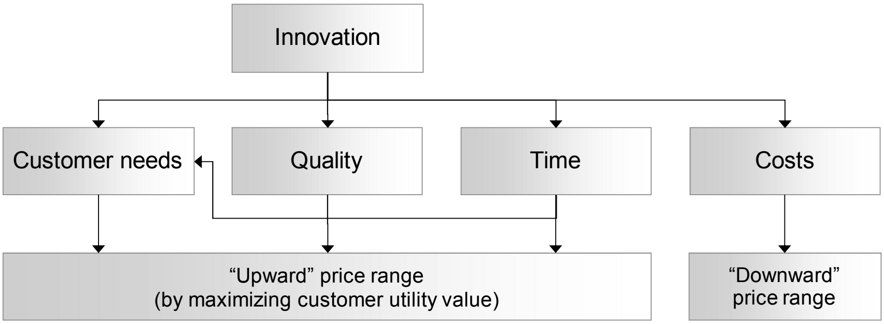

Fig. 1.1: Increasing profitability through innovations

Innovation is largely driven by new technologies, especially overarching technologies that produce a wealth of different applications in a wide range of sectors, such as information technology or nanotechnology.

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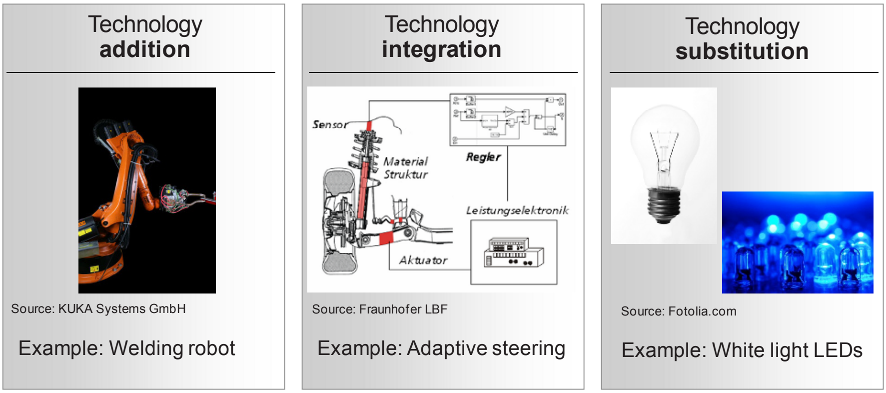

Fig. 1.2: Three types of technology development

We distinguish between three types of technology development as relates to their effect in new products (Fig. 1.2).

Additive technology development combines two or more technologies to create a new product. The combination of a robot with a welding gun, for example, enables automated production of car bodies. The challenge faced by the company, in this case the robot manufacturer, is that of combining robot technology with welding technology. The problem can usually be solved with the aid of suppliers. Should more major interface problems occur, it may also be necessary to enlist the help of partners in research and development.

The integration of several technologies, which in our example involves integrating mechatronics (mechanics, electronics, software), optoelectronics (optics and electronics), nanoelectronics and biomimetics to produce adaptronics, opens the way for completely new functions such as a self-adjusting steering mechanism or adaptive undercarriage characteristics. The interdependency of these partial technologies is considerably more diverse and intensive than in the case of additive technology development, meaning that integrative technology development calls for a greater degree of interdisciplinary cooperation and presupposes the participation of several research and development partners and suppliers.

Both types of development, integrative even more so than additive, require that the company be capable of successfully developing new products in an open innovation system.

Because product functionality becomes more complex in both cases, process complexity and ultimately also system complexity in terms of cross-company cooperation likewise increase. More than anything else, the rapid acquisition of new skills and expertise entails difficulties and thus becomes a barrier to innovation. What we understand by innovation, therefore, is more than simply inventing and developing a new technology or a new product. That is only the first step, the invention. Not until it is successfully marketed does an invention become an innovation.

The risks involved in both types of technology development are thus to be seen in the expansion of know-how and the mastering of complexity. Usually, though, existing knowledge does not lose its value. In our examples, the partial technologies or part products such as robots, welding guns, mechatronics, optics etc. can still be successfully marketed.

This is not true of the third type, technology substitution, in which a technology or a product based on that technology – say the electric light bulb – is replaced by something new, in this case the LED. Existing knowledge is thereby rendered partially or completely obsolete, so that the company finds itself facing a serious threat (TUSHMAN & ANDERSON 1986). A particular problem arises if, despite recognizing the threat, the company fails to realign its strategy rapidly enough due to the inherent inertia of the system, the processes and so on. This is known as path-dependence (SCHREYÖGG et al. 2003), or you might say "success is blind".

Obviously, there are no clear dividing lines between the various types of technology development. It is conceivable that, after several spurts of development, an additive development such as the hybrid engine may to some extent transmute into a substitutive technology because the combustion engine plays a less important part in the technology network than hitherto. Integrative technology development, too, can start out as a simple addition and then become a complex networked development as it is expanded to include electronic components, sensors and feedback control systems.

A further distinguishing mark of the impact of a new technology on innovation is its scope within a product. It is possible that (a) new parts, assemblies or modules will be created, or (b) the product architecture will be changed (HENDERSON & CLARK 1990) (Fig. 1.3).

A car engine is an excellent illustration of the fact that pursuing the development of a 4-cylinder Otto engine to create a 6-cylinder engine will affect assemblies and parts, but the architecture, i.e. the fundamental structure and the basic operating principle, remains unchanged. The hybrid engine, on the other hand, is an extension of that architecture. The electric and electronic functions and the fuel cell ultimately change the architecture completely, and this affects the entire drive train.

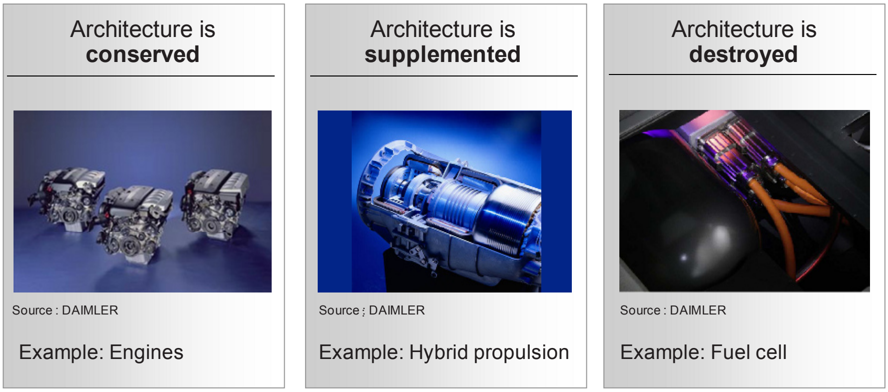

Fig. 1.3: Extent of innovation

Different companies are affected by technology development to differing extents, depending on their supplier status. If the architecture is conserved, there is no need to change the relationship between OEMs and suppliers. If the architecture is supplemented, a technology integration problem that requires additional partners is created, at least for the engine manufacturer. The destruction of the architecture causes a substitution problem for the engine manufacturer that leads to completely new development and supply structures. The two latter-named changes are not as radical for the OEM as for the suppliers of engines or gearbox parts and modules, as they do not destroy the functionality of the vehicle as a whole.

So what part does technology development play in company innovations?

We can distinguish between four types of innovation (Fig. 1.4):

Incremental innovation is a step-by-step enhancement of tried-and-tested technologies and familiar customer requirements. This is the most frequently encountered type of innovation. Its advantage is that it involves little risk; its disadvantage can be termed the "incremental trap". Numerous minor technical expansions lead to high product complexity, for example, caused by a large number of functions which result in high costs and/or a decline in user acceptance. Examples include complex telecommunication products or major software systems.

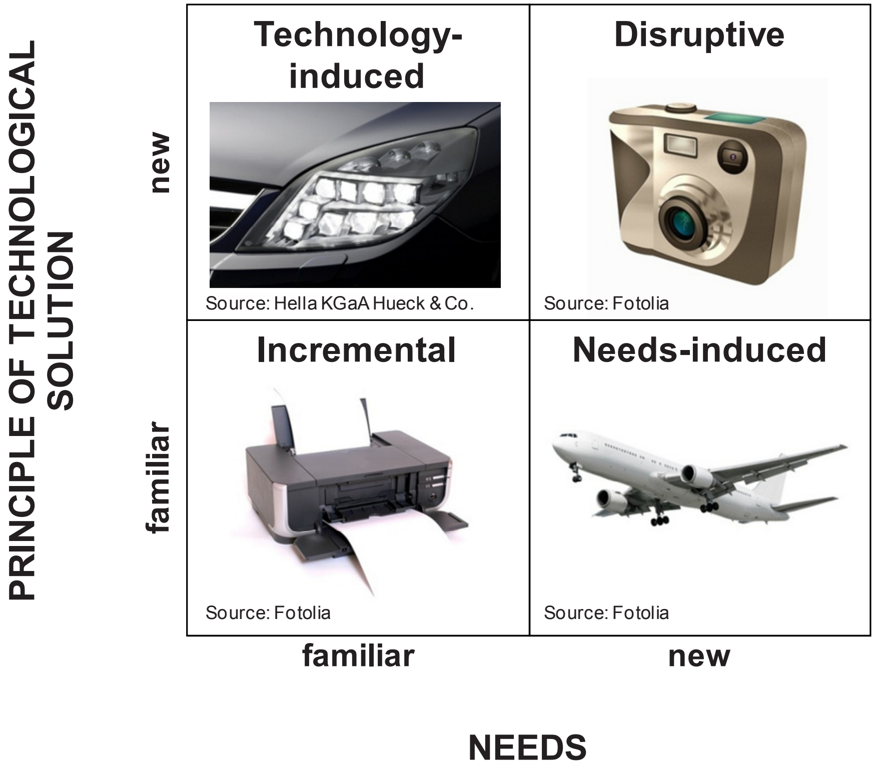

Fig. 1.4: Innovation portfolio

Needs-induced innovation wins new customers for tried-and-tested technologies, e.g. by means of a new business model such as low-cost airlines. Other pertinent examples include leasing rather than buying a car, or operator models in which manufacturers do not sell machines, but instead deliver and invoice finished parts. But technologies can also be a decisive factor in needs-induced innovation. Low-cost online flight bookings, for instance, are only possible thanks to the Internet.

Technology-induced innovation discovers new technical solutions for recognized needs. Examples include LED lamps in cars, or the plasma and LCD monitors that have taken the place of CRT screens for televisions and computers. In this case the new technology is substitutive and may present a threat to companies that are too deeply rooted in traditional technology.

Disruptive innovation plays a particularly important role (CHRISTENSEN 2000, DANNEELS 2004, CHRISTENSEN 2006). It enables new customer needs to be satisfied with new technology, and is thus more radical than the other types of innovation. Those who address this type of innovation at an early stage can tap new markets and achieve a huge innovative leading edge. One example of disruptive innovation is digital photography, which has destroyed the existing manufacture of cameras along with the value chain of film production, film development, and print production. This is offset by the manufacture of digital cameras and of printers for printing out copies at home. In addition, cell phones have been transformed into cameras with the ability to transmit pictures directly via the Internet.

It is a widespread assumption that disruptive innovations always take place at the "upper end" of the technological achievement scale. This assumption has been fueled by examples such as the DVD, which has a higher capacity than the video cassette. However, innovation often takes place at the "lower end" of the technology scale. The first PC, for example, was a great deal less powerful than the mainframe computers customary at the time, and that still holds true today. The innovation in this case is that of individualization. Just as with the different types of technology development, transitions take place from one type of innovation to another. An additive technology development, for example, may have been planned as an incremental innovation. The outcome of further research and development turns it into a technology-induced innovation, and it ultimately acquires the status of a disruptive innovation because it caters for completely new needs and taps completely new markets (Fig. 1.5).

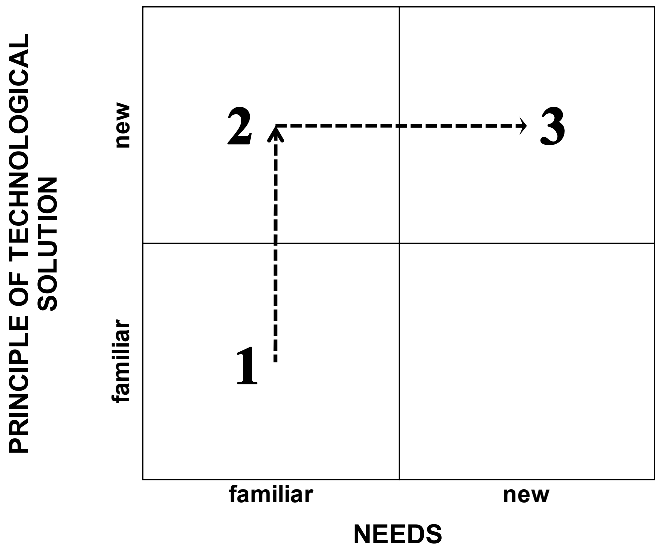

Fig. 1.5: Innovation paths

One such example is the MP3 standard. Originally developed for satellite-based telephony (1), this audio data compression technique opened the way for new products such as the MP3 player (2). Applying this standard on the Internet makes it possible to carry out music downloads that have a disruptive effect on the entire music sector (3). The reason is that entirely different value-add principles can and must be implemented because the original principles, e.g. the sale of CDs, are no longer adequate.

If we combine technology-oriented, disruptive and needs-oriented innovation under the heading of radical innovation and contrast them with incremental innovation, while at the same time distinguishing between product innovations and organizational innovations, we can identify certain interrelationships between the type of innovation and technology development and of organizational development as shown below (Table 1.1).

Table 1.1: Incremental versus radical innovation

Innovation	Product	Organization
Radical	► Integrative technology development that changes the architecture or ► Substitutive technology development that destroys the architecture	► New business models ► New value chains
Incremental	► Additive technology development that conserves the architecture	► Improvement of business processes

Incremental product innovations are confined to additive technology developments that conserve the existing architecture. In the area of organization, this involves carrying out improvements to business processes.

Radical innovations, in contrast, are generated by integrative or substitutive technology developments that change or destroy the existing architecture. In the area of organization, this involves creating new business models and new value-add networks.

This classification enables us to characterize typical innovation patterns in companies (Fig. 1.6).

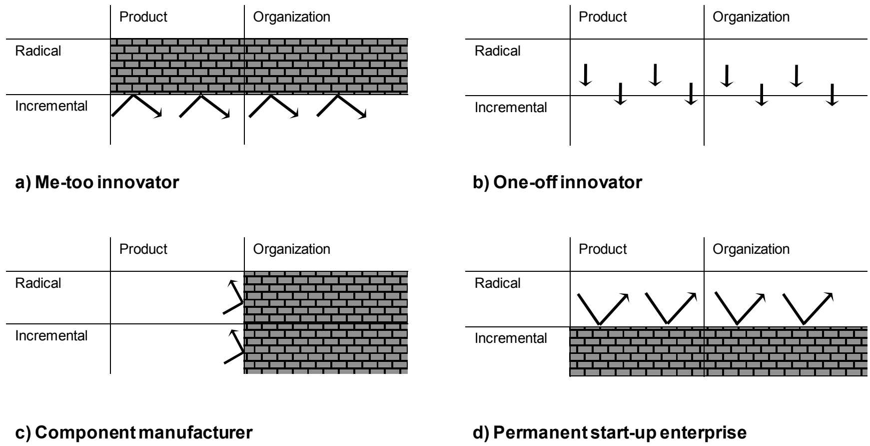

Fig. 1.6: Typical innovation patterns of companies

Incremental "me-too" innovator

The company is proficient in incremental product development and continuously improves its business processes in order to save costs. However, it has difficulty in crossing the line to radical innovation. It faces the risk of declining growth and low profit margins (Fig. 1.6a).

One-off innovator

The company gained its reputation through a radical innovation and possibly a new business model developed by a person such as its founder. However, as this is not followed up by any comparable innovation, the company rapidly reverts to incremental status and faces the same problems as the "me-too" enterprise (Fig. 1.6b).

The innovative component manufacturer

The company has very good technological capabilities and is in a position to carry out radical technology developments which it continuously improves, but it does not succeed in properly capitalizing on this capability by setting up new business models (Fig. 1.6c).

The permanent start-up enterprise

The enterprise constantly produces radical innovations, but it is not capable of moving beyond prototypes and initial product versions to achieve a continuous market roll-out. It is a typical candidate for takeover (Fig. 1.7d).

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2 Production Technology in High-Wage Countries – From Ideas of Today to Products of Tomorrow

Fritz Klocke

1 The Polylemma of Production in High-Wage Countries

Competition between manufacturing companies in high-wage and low-wage countries typically occurs within two dimensions: the production-oriented economy and the planning-oriented economy (BRECHER et al. 2007). Low-wage countries' productions economically compensate possible disadvantages within process times, factor consumption and process mastering by low productive factor cost. In contrast, companies in high-wage countries try to maximize the economies-of-scale – that is, the utilization of the relatively expensive productivity factors. More and more unit cost disadvantages arise for high-wage countries, which they try to compensate through customizing and fast adaptations to market needs, economies-of-scope. The share of production within the value chain decreases more and more. Thus the realizable economies-of-scale decreases too. The escape into sophisticated niche markets is not promising, either.

Within the second dimension – the planning-oriented economy – companies in high-wage countries try to optimize processes with sophisticated, investment-intensive planning systems and production systems while companies in low-wage countries implement simple, robust value-stream-oriented process chains. Since processes and production systems do not reach the limits of the optimal operating point, additional competitive disadvantages for high-wage countries emerge.

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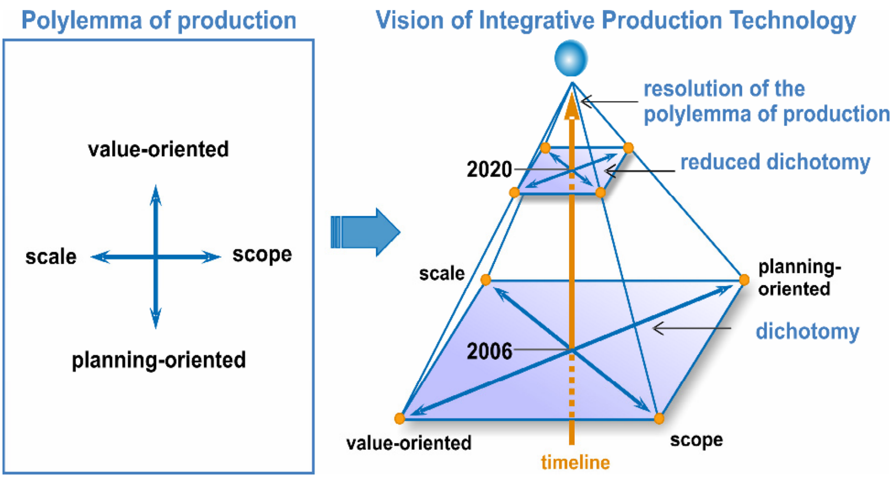

Fig. 2.1: The polylemma of production

To achieve a sustainable competitive advantage for production in high-wage countries, it is not sufficient to achieve a better position within one of the dichotomies "scale-scope" and "planning-orientation vs. value-orientation". The primary aim should be the resolution of both dichotomies, the **polylemma of production** (Fig. 2.1). That means economies-of-scale and economies-of-scope must be optimized at the same time. Additionally, the share of added-value activities must be further maximized without neglecting the planning quality and optimization.

2 Approaches to Resolve the Dichotomies in Production

2.1 Value-Oriented Production Technologies – Knowing how to Create Value

The goal of generating values in a targeted way refers to the processing of production know-how and the application of correct strategies. Both aspects together represent decisive potential for increasing added value in production companies. In the case of complex processes, it is advisable to analyze and optimize important operational sequences in advance by means of models and simulations. Matters to consider include batch-size planning, utilization and capacity planning, logistics issues and the modelling path from the CAD model to the production program of the machine. The more precisely the target and result scores are defined during this planning phase, the greater the planning efforts involved.

Due to the decreasing costs of computing power and improved software applications, very good method and modelling tools are available today, thereby opening up considerable capacity potential during the planning stage. By contrast, the planning and optimization activities that are more closely related to the process and the machine focus on the goal of gaining and processing information on site from the process itself, and to implement this in real-time strategies, so that processes may be controlled into optimum operating points online. The principal of both goals is justified. What is important, however, is to merge the planning- and value-oriented approaches in an optimum way. Particularly by employing approaches and models for achieving the self-optimization of production processes, it is possible to find new ways of bringing about increases in efficiency. To do this, it is necessary to systematically discuss issues relating to the recording of the actual situation, to the definition of optimization goals and to the strategies that will be employed, and to implement the solutions in robust working environments at a high level of process reliability. The central question can be defined as follows:

How can product value and production value in a high-wage country led into a new, balanced relationship?

Here it is important to consider that measures and models aimed at eliminating the contradiction between planning- and value-oriented production may also have implications for the contradiction between large-series production and individualized single-part production.

From a production point of view, the production value is largely determined by operating costs, personnel costs and the number of parts produced per unit of time. Value-oriented production technology needs to unite these focal points of interest. In order to analyze this aspect in more detail, the reference framework shown in Fig. 2.2 has been established.

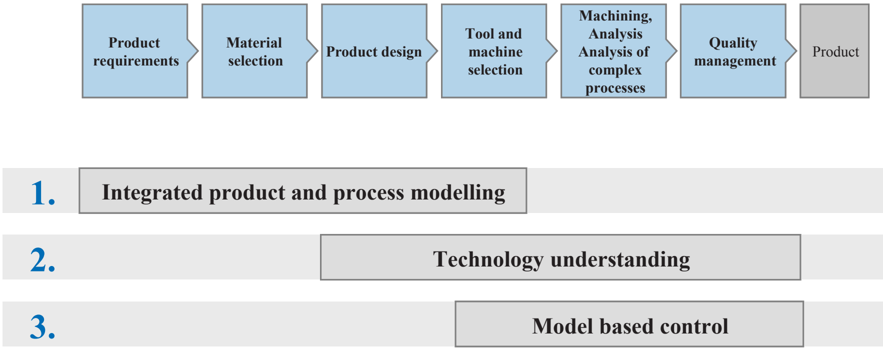

Fig. 2.2: Elements of value-oriented production (KLOCKE et al. 2008a)

The value-adding chain shown in Fig. 2.2 encompasses the areas of production planning, production and assembly. In selected cases, the analysis framework is expanded in the following to include product development. This is because questions relating to functional integration and the redesign of products are always closely related to production issues.

2.1.1 Production Planning

Production planning is characterized by process, planning and production requirements, as well as material planning and scheduling. In order to be able to carry out an integrated value analysis during the planning process, it is also necessary to incorporate research and development, design and production management into the production planning process.

From a technological point of view, PLM systems provide continuity in communication from the management to the production level. They can serve to integrate and collate all product data, thereby contributing to the digitalization of the information flow. The coupling of research and development, design and production to the planning processes by means of software allows the entire, highly complex product lifecycle to be better controlled and incorporated into the management structures. Digitalization results in missing interfaces being bridged by making all data available to all areas. Figure 2.3 shows an approach for achieving complete data integration (TIA – Totally Integrated Automation).

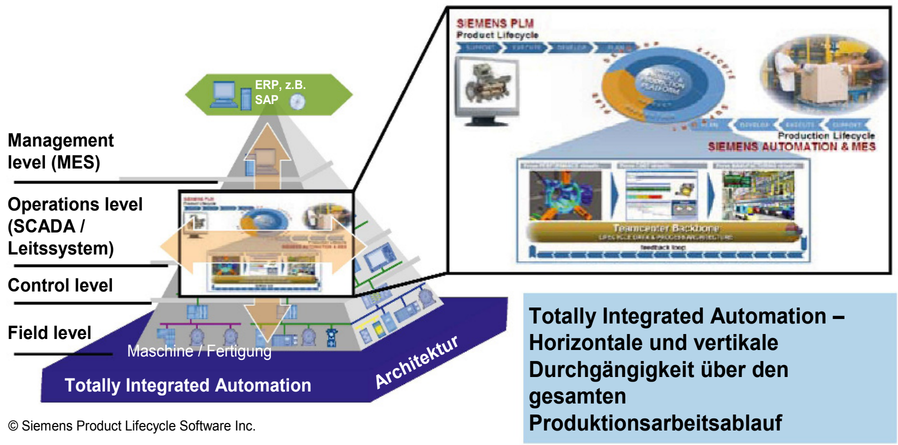

Fig. 2.3: TIA – Totally Integrated Automation (KLOCKE et al. 2008a)

TIA refers to the implementation of an entirely continuous, integrated planning process that guarantees continuity in a company from the SAP level to the CAD-CAM coupling as well as to the data interface on the machine control systems. TIA is intended to link activities from product design, the set-up of production structures and the tasks of the production management. At the same time, it should also connect to the ERP system, to company structures and to existing production systems. The challenge of such a digital system solution lies in managing and structuring the data volume that is generated, as well as in ensuring the necessary transparency for the individual users.

Global relocation of production to emerging countries is carried out to tap new markets, among other things. The local presence demanded of companies in order to be able to guarantee delivery reliability and flexibility, as well as the necessity to produce locally (local content), causes companies to relocate their production activities (KLOCKE et al. 2005). The choice of production location is thereby also determined by the economic efficiency of production. Figure 4 shows a case study from forging technology that is based on some basic assumptions that will be outlined in the following. In this example, production at various locations with different location costs are compared under cost considerations.

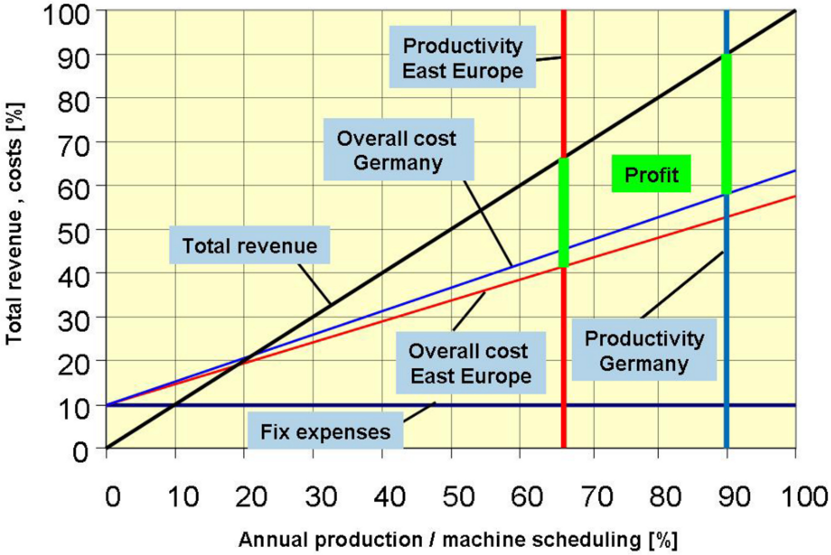

Fig. 2.4: Case study of economic efficiency in forging production (KLOCKE et al. 2008a)

In this case study, the profit of the company located in Germany is – in spite of higher operating costs – higher than that of the one located in Eastern Europe. The calculation of the net profit is based on the prerequisite that the capital costs (here fixed costs) are identical at both locations. It is also assumed that the operating costs in Germany are somewhat higher than at other locations and that higher production figures are covered by market demand. The decisive difference in this case study results from the higher productivity prevailing in Germany. The underlying total productivity is highly dependent on the degree of machine utilization and on the availability of the production facility. Experienced employees in Germany ensure rapid machine ramp-ups; they can make sure that any process faults occurring are eliminated quickly and in a targeted way, with any necessary servicing being carried out promptly. This has a direct impact on productivity. This example very clearly reveals that merely considering wage costs leads, in many cases, to false conclusions. When it comes to the choice of location, it is always the entire value-adding chain that is decisive. Many rash decisions to relocate production to low-wage countries were not made after sufficient consideration of these interrelating factors, leading to many companies having to undertake expensive measures to relocate back again.

2.1.2 Flexibility

Questions relating to the flexibility and adaptability of production facilities are decisive capability characteristics. The effects on the Economy of Scales und Economy of Scope also have an effect on the question of value-orientation and the value contribution of production. For this reason, additional considerations are integrated in the following under the main topic of flexibility and adaptability. These considerations may be viewed under the theme of “Knowing How to Create Value”.

Under the term “production flexibility”, an additional aspect is brought to bear when it comes to the existing advantages of producing at locations in highly developed industrial nations. Germany, in particular, with its high level of education and training and its very good technical infrastructure, can achieve great value advantages in this respect. For many production systems, the goal is to simplify processes, simplify products and to harmonize workflows. This guideline opens up many opportunities, particularly if the product complexity is low. Due to the level of education and training provided there, Germany is, however, also very well equipped to be able to produce even complex products at a high level of performance and productivity. This will be outlined in more detail in the following.

A very good example of production flexibility is found in the manufacturing of highly complex, functionally integrated compressor and turbine sets in blisk design (blade integrated disks). The advantages of this integrated design detailed in Fig. 2.5, which lead to weight reductions of up to 30%, improved aerodynamics as well as a reduction in fuel consumption and in exhaust volumes, demand complex production prerequisites. Irrespective of the blade length, the established processes for producing the blisks include friction welding, high-performance milling and, for certain geometries, ECM (electro chemical machining).

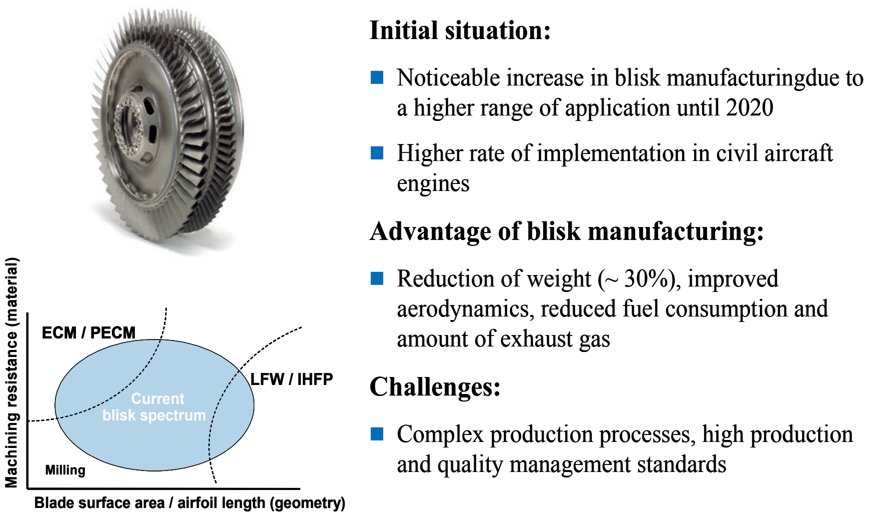

Fig. 2.5: Flexibility in blisk production (KLOCKE et al. 2008a)

2.1.3 Technological Capability

A necessary prerequisite for operating production in high-wage countries is to design complex products with a high level of functional integration and to develop the fundamental capabilities for the manufacture thereof. Technological capability is the prerequisite for being able to produce complex products at a high level of performance. Here, robustness and process capability play a decisive role. In addition, the development of generic models and methods are needed with which self-optimizing production processes may be designed. A primary target value is a product quality constant over time across the entire lifetime of the produced components. Besides this, the methods and models must have a sufficiently high level of transparency in order to guarantee transfer to other workpieces, other operating conditions and other machines. The monitoring and active control of all production processes require detailed and systematic decoding as well as the logging of all machines and data relating to the product, the process and the sensor. On the basis of this, it is then possible to develop suitable algorithms which flow into new operating structures. One particular challenge arises from the fact that questions of stability must be taken into consideration, especially when producing filigree parts. The processes must not be allowed to drift into impermissible ranges due to stochastic influences. If this entire field is mastered then the basic prerequisites are created for implementing process monitoring that is integrated into the production process. This opens up another area in which production potential may be rendered utilisable.

It is expected of high-performance processes that they can be led, in a reliable way, to work at their technological limit with low scatter. In order to master this performance portfolio in an assured way, the capabilities presented in the following headwords must be developed or extended in a targeted way.

- Value-creating application of manufacturing technologies
- Maximization of technological performance
- Monitoring and control of manufacturing processes
- In-process monitoring of the product quality
- Combination of technology knowledge

Through the collaboration of different R&D areas, the combination of technological know-how and the bundling of individual competence areas, further product developments and value increases may be driven forward to a significant extent. Furthermore, companies and production locations in Germany must stand out through distinguishing characteristics, as these represent a competitive advantage over rival companies and overseas locations (REHSE 1998). The term “lead production” refers in Germany to a strategy in which the relevant advantages of the location may be used in a consistent way. Technological know-how and technological capability are clear performance characteristics by means of which companies can distinguish themselves from the competition.

When it comes to production, the product functionality decides on the basic suitability of the process chain used. Quality demands and functionality determine and describe the requirements placed on the end product. Often unnecessary costs are incurred due to the selection of overly ambitious characteristics and tolerance limits in individual process steps. The approach of optimizing individual machining steps with respect to the entire process chain represents a contribution to value-oriented production. Under the aspect of technological capability, the optimization of the process chain is not necessarily the same as optimising individual process steps. Individual process steps must be designed and harmonized with each other in such a way that they do not exceed the precision requirements of the subsequent production processes.

2.2 Integrated Production Processes – Scope of Technologies for Serial Manufacturing of Specialized and High Value Added Products

The demand for manufacturing systems with a flexible configuration has seen an increase over the past few years that is far above average. Particularly in high-wage countries, the machine and plant manufacturers have documented new sales records for flexible machining centres, manufacturing cells and transfer lines as well as for customized solutions. Flexible machining centres for cutting operations, for example, achieved a 38% increase in production compared to the previous year (1st–2nd quarter 2007). At a production value of 781.7 million euros, they achieved the largest market share (14%) among cutting machine tools (STATISTISCHES BUNDESAMT et al. 2007).

The increased use of flexible manufacturing systems is a reaction on the part of manufacturing companies to the trend towards the individualization of consumer and industrial goods and to the resulting necessity to process small batches at a high overall volume (Fig. 2.6). The industries affected by individualization include medical engineering as well as machine, plant and tool manufacturing; to an increasing extent, the supply industry for automotive and aircraft construction is also affected. With respect to the parts being produced, the individualization process mainly affects the geometrical characteristics (dimension and shape), the surface/rim-zone properties and the material.

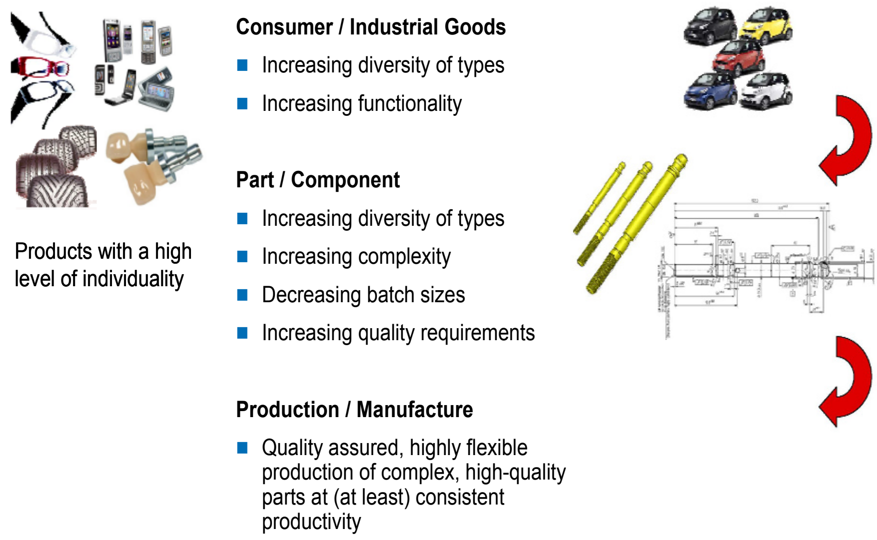

Fig. 2.6: Production requirements (KLOCKE et al. 2008b)

Classic manufacturing systems usually consist of several specialized individual systems that carry out only a few machining operations or one very specialized one on the part. Flexible manufacturing systems, by contrast, are characterized by a higher level of flexibility in the individual system and thus by a significantly higher flexibility across the entire system. The basis for a flexible manufacturing system is formed by cleverly linking conventional and new production technologies in a specially designed plant/system solution. This enables process steps to be compacted (with respect to both time and place), leading to the expansion of system functions and to the significant acceleration of the machining processes, e.g. through reductions in the primary and auxiliary process times and particularly in the set-up times. Typical examples of a flexible manufacturing system are modern turning/milling machining centres which are increasingly replacing classic machining on different facilities.

2.2.1 Designing Scope of Technology – Increasing Product Flexibility and Maintaining Productivity

Manufacturing companies usually produce several products (types) which are generally classified into product groups. The products in a product group always demonstrate a high degree of similarity with respect to their geometrical and material properties. If the overall differences between the products in a product group are only negligible, they may be produced in a flexible and economic way using comparatively simple manufacturing technologies. Examples of such products include turned parts with different outer contours. Due to the comparatively low set-up and programming efforts involved, these parts may be produced economically and efficiently in almost any batch size using NC turning machines.

It is a different situation when it comes to parts which differ from each other in several features and which are thus characterized by a considerably high level of complexity. Here the current production concepts rapidly come up against their economic and technological limits. The generation of relevant product groups requires the use of several separate machines and facilities. The entire system (manufacturing system) is technically complex and costly both to procure and to operate. Particularly costly are systems in which the machines are linked mechanically and in their control system in order to achieve automated material flow. With decreasing batch size, the throughput times of the parts in a complex manufacturing system increases disproportionately. A major reason for this lies in the increasing set-up and programming efforts. Economic production of small batch sizes is thus limited in complex manufacturing systems to a few simple products.

The production of complex product groups in small batches using complex manufacturing systems poses a problem not only with respect to costs. Challenges arise from technological aspects, too. The spatial separation of the individual processes means that the advantages of machining in one clamping process, which lead to the avoidance of dimensional errors due to reclamping, or lower transport damage, may not be exploited. Furthermore, the potential reduction in the time needed for individual processes cannot be tapped to a sufficient extent. Rapid process sequences or even a parallelization in mechanical and thermal processes, such as milling and deposit welding for generating unique geometrical and material properties, may only be achieved to a limited extent. Likewise, the advantages of hybrid processes, i.e. a simultaneous combination of two single processes, such as the generation of special surface properties through laser-assisted cutting technologies or the expansion of the material spectrum during laser-assisted spinning, may only be exploited to an insufficient extent.

The manufacturing systems available on the market today are the result of development processes with different aims. On the one hand, they represent physically-oriented technological innovations. These are usually based on the active principles of mechanical, thermal or chemical processes for the separating, joining, primary shaping and forming of parts. Singular manufacturing systems are the result. While some of these facilitate highly flexible machining operations, they only permit linking to other processes to a limited extent. On the other hand, manufacturing systems always represent the result of a product-related development. Using a product as the starting point, technologies are then sought which allow the product to be manufactured at the required level of quality. Often alternative production options are identified. The option which is then chosen is always the one which may be implemented technologically in a manufacturing system and which represents an economically feasible solution.

Particularly when producing complex parts, the optimum choice and linking of suitable technologies represents a comprehensive production engineering challenge. The dependencies and interactions among the production technologies as well as between the production technologies and the tool systems and machines have not been modelled systematically and in their entirety to date. Initial approaches (models, methods) have only existed for sub-systems up to now. In an industrial context, the development of a production solution is thus largely based on the experience and know-how of the production engineer.

Due to the lack of methods, flexible production solutions developed to date largely build upon the technological or product-oriented solutions outlined above. Only in a few exceptional cases do they represent a targeted innovation or development that is oriented to product groups and that is thus also flexible. One reason for this is the lack of an appropriate comprehensive complexity frame. Rather, in the case of highly complex products, the product-oriented approach is chosen in order to be ultimately certain of solving the production task. This narrow flexibility margin leads, in turn, to greatly limited system flexibility, thereby precluding all alternative solutions. If the approach is aimed at developing a flexible production solution, however, it is not only specific products with a high level of complexity that may be produced, but also other parts that are characterized by different complexities or even simple parts. The production concept may thus be used at a higher degree of flexibility.

The development of manufacturing systems that are specific to product groups demands that the processes, tools and machines within the system are taken into account. In order to reduce complexity, three technological features may be used in a representation model (Fig. 2.7) to assist in depicting the flexibility of the manufacturing system with respect to product groups:

- Number of system-integrated production technologies
- Adaptivity of the system-integrated tools
- Kinematic freedom of the system and its sub-systems

The greater the number of production processes integrated into a system, the greater the freedom of scope during processing with respect to geometry and material. Adaptive tools likewise increase processing flexibility. Tools which adapt to part-specific geometries via control systems with actuators and sensors, for example, increase the freedom of scope with respect to geometry and replace the time- and cost-intensive set-up procedures required with tools that are inflexible with respect to geometry. Tools such as power-controlled laser beam tools, which can adapt to certain material properties, increase the flexible material spectrum that may be processed by the tools. Finally, the processing flexibility also increases with the kinematic freedom of the system and its sub-systems. Here it is important to utilize synergies between sub-systems in order to reduce the overall costs for system and plant engineering (e.g. the number of axes necessary, control technology). The goal must be to implement several sub-processes on the basis of a kinematic system that can be applied across many kinds of different processes. A modular set-up of the sub-systems and new types of mechanical, electrical, optical and control interfaces are examples of how this may be achieved.

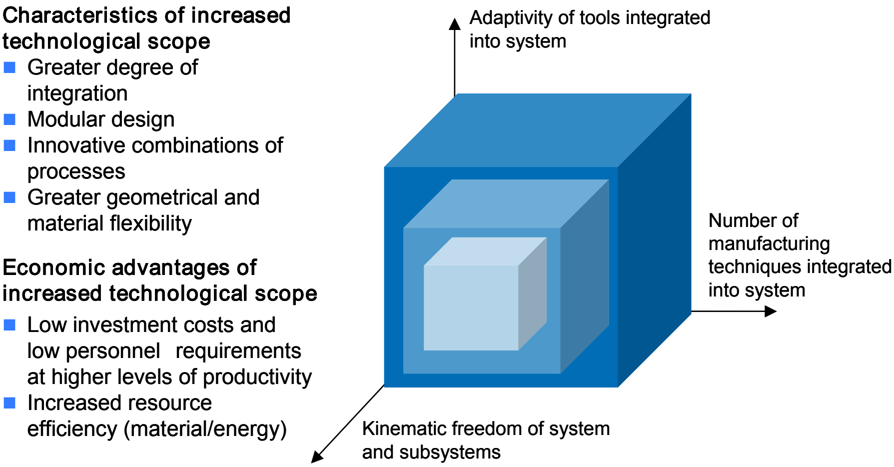

Fig. 2.7: Characteristics and advantages of extended scopes of technology (KLOCKE et al. 2008b)

Correlations between the individual features described may not be disregarded, however, when setting up a new, flexible system solution. Improvements to one feature must not be made at the cost of the other two features. If dependencies are properly taken into account, the three individual features span a new scope of technology that describes application possibilities with respect to geometry and material and thus the production flexibility of the manufacturing system with respect to product groups.

In order to be able to develop the scopes of technology characterized by the three technological features, it is necessary to generate development activities in different areas adapted to the product groups. These activities take place on the one hand at a production technology level and treat aspects of the individual processes, sequential or simultaneous process combinations or technology chains. On the other hand, they deal with aspects relating to plant and system engineering as well as mechanical systems, tools, control technology and process monitoring. The targeted, i.e. product-group oriented, combination of these areas of activity ultimately determines the scope of technology and thus the degree of capability of the manufacturing system to deal with the different manufacturing complexities.

Redesigning scopes of technology and creating additional scope must begin with the analysis of the relevant product spectrum and the associated technology and production chain. The production technologies used and their interactions must be identified and described with respect to their part function. The following examples from an industrial context should illustrate this procedure and demonstrate the potential of new product-specific scopes of technology.

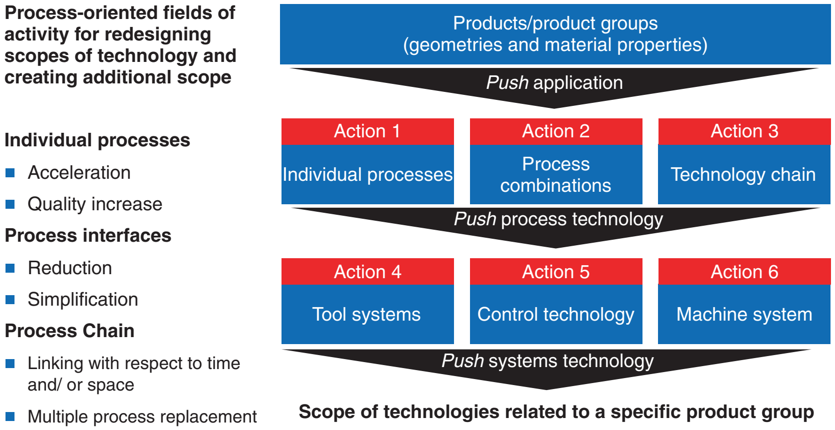

Fig. 2.8: Areas of activity for designing scopes of technology (KLOCKE et al 2008b)

2.3 Functionalized Surfaces

Surfaces of many different technical products, as e.g. solar cells, optics, medical products or in automotive industry are fulfilling more and more a technical function rather than being only a physical barrier. Micro structures or coatings transform simple components into (multi-) functional elements. Nowadays functional surfaces have a deciding influence on the performance of a product. Furthermore, the characteristics of a product can be varied by applying different functional surfaces. In this way functional surfaces enable high performance products which permit market leadership by uniqueness and empower and enduring growth of companies in high-wage countries. A big challenge for science and engineering is the understanding and the manufacturing of functional surfaces. Especially high-wage countries with their interdisciplinary orientation can face this challenge. The intense connection between industry and sophisticated research entities ensure and strengthen the position of high-wage countries in the global market.

2.3.1 Functional Surfaces as the Key to Innovations and Competitive Advantage

"God created the volume, the devil created the surface" – this sentence is attributed to the physicist and Nobel Prize winner Wolfgang Pauli. With this statement he makes clear that a surface sets clear limits to the well-ordered and well-understood world of solid bodies – a world that is characterized by consistent material parameters. On the one hand for production engineering this means that the applied technologies need to be adapted to the surface properties of the solid to be processed. On the other hand, it also means that every operational process causes the properties of a surface and thus its functionality to be altered. Innovative machining and coating processes may therefore be used to develop and optimize functional surfaces for numerous applications in a targeted way.

Functional surfaces extend the properties and thus the application possibilities of technical products. Local functionalization may be achieved by various processes (coating, structuring, etc.), either individually or in combination. Examples include micro structured surfaces which, depending on design, lead either to water droplets rolling off them and thus to a self-cleaning effect ("lotus effect"), or to a considerable reduction in flow resistance ("sharkskin effect"). The list is endless and shows that processes for surface functionalization represent cross-sectional and key technologies which play an important role in almost all areas of mechanical engineering, automotive engineering, optics, as well as in energy and medical engineering.

Within the polylemma of integrative production engineering (Fig. 2.9), the functionalization of surfaces may be classified under the axis of value generation. The targeted enhancement of surfaces provides a product with additional properties or even leads to the generation of completely new products. It is therefore important **to generate values with the right technologies today in order to be competitive tomorrow too.** This allows a significant added value to be generated in a product – an added value that is consciously demanded by the user.

In order to develop functionalized surfaces, the competence of engineers and specialists is required. These prerequisites are given in high-wage countries and provide the manufacturing companies there with the opportunity of differentiating themselves from the competition in low-wage countries and of achieving a decisive market edge.

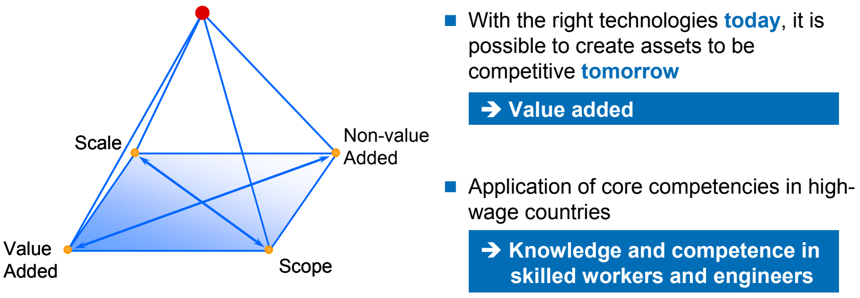

Fig. 2.9: Classification of the topic within integrative production engineering (KLOCKE et al 2008c)

Some examples in which a differentiation from and a decisive advantage over the competition can be achieved are shown in Fig. 2.10.

The key lies in the details; the details determine the performance

Increasing product value is achieved here by modifying the surface structure on a microscopic scale. These microscopic modifications ultimately determine the performance of the product (e.g. micro structured foils for increasing reflectivity). Production engineering is thus faced with the challenge of producing microscopic modifications on a macroscopic scale – and this in a stable and economically justifiable way. **"Mastering complex miniaturization" is the challenge and also the opportunity for achieving a unique market position.**

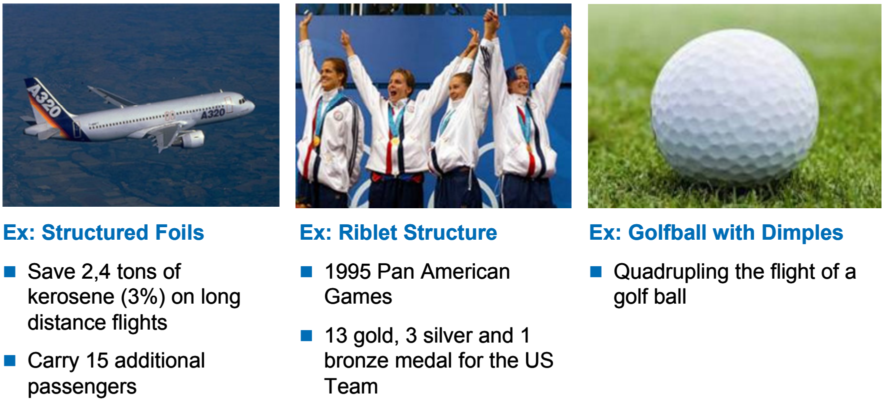

Fig. 2.10: Uniqueness and market edge through surface functionality (source: Airbus, IOC, MEV) (KLOCKE et al 2008c)

3 Conclusion

The competition between high- and low-wage countries typically takes place comparing the economy/value-oriented and scale/scope-based production. In this context there are two dichotomies which have to be resolved. In order to achieve this three different approaches are presented.

The term "value-oriented production technology" is illuminated within the topic areas of production planning, flexibility and technological capability. In order to "know how to create value" and to be able to produce new products, Germany as a business location must differentiate itself from others by operating production processes in such a way that complex processes can be employed which still demonstrate a high level of robustness and a high degree of flexibility. In this context it is revealed that the development of new values is accelerated by a combination of technological know-how in different areas of competence. Although good opportunities do, in principle, exist for producing complex products in Germany, it is clear that new approaches are required which allow processes to be analysed, modelled and mastered.

In order to achieve a sustainable competitive advantage for production facilities in high-wage countries, one must find ways of increasing the variability and individuality of products while at the same time producing them at mass production prices. This is made possible through efficient processes that have been optimized in terms of added-value and whose performance is not impaired by excessive degrees of planning or organization. Current manufacturing concepts such as machining centres, flexible manufacturing cells and systems that deal with conventional variations in production run sizes provide the initial solution. These concepts are, however, too rigid and slow to deal with any dynamic changes in production run sizes or with individualized production down to a production lot of »1«. Redesigning the scope of technology and creating additional scope leads to the generation of new system solutions that make significant advances in this direction. By integrating and combining the characteristic features of the aforementioned concepts, this approach will also improve those characteristic features. The extreme extent to which technologies are integrated and modularly combined makes it possible to harness the capability of new manufacturing technologies as well as process combinations and improve on the long-term production efficiency and quality.

Functionalized surfaces are enablers for high-performance products whose innovation ensures sustained growth in Europe. They provide a decisive extension of product properties which often generate unparalleled products. The market leadership of European companies that is generated by new products can be used to strengthen and extend their market position. The development of functionalized surfaces for solving existing challenges or even for creating completely new products (product characteristics) requires close cooperation between applied research and industry as well as an advanced infrastructure. These prerequisites are given in high-wage countries and provide the manufacturing companies there with the opportunity of differentiating themselves from the competition in low-wage countries and to achieve a decisive market edge.

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3 Innovation Champions – Or How to Achieve (Global) Competitiveness!

Klaus Henning, Andrea Huson

1 Challenges of a Modern Working Environment

At the present time, all modern societies experience changes in socio-economic terms and go through far-reaching processes of change in economic and social structures. Examples of dilemmas that characterize these processes are tightened stress of competition, short product and innovation cycles, a continuous adjustment of qualification standards and an increase of flexible, unsecured employer-employee relationships (HENNING & LEISTEN 2007).

Even Germany and Europe have to face these challenges to stay competitive in the global markets of the 21st century. Under these conditions, the future scenarios agree on the perspective 2020 (Fig. 3.1): China, India, the Americas and Europe together with Russia will be the new economic area of the future (SCHARIOTH et al. 2004; BRÜHL & KEICHER 2007). Most likely, Europe will only be able to establish itself as a worldwide main economic area in close cooperation with Russia, at the present time one of the most dynamic markets.

How can Germany, as a part of the European Union, get to play an important role in this contradictory context? Which future perspectives must thereby be considered?

In order to keep Germany competitive in the perspective 2020, the expected tendencies of future social, economic and political developments have to be considered. In the following, the framework of requirements will be discussed in three clusters of the future: Working 2020, Learning 2020 and Development of Competencies 2020.

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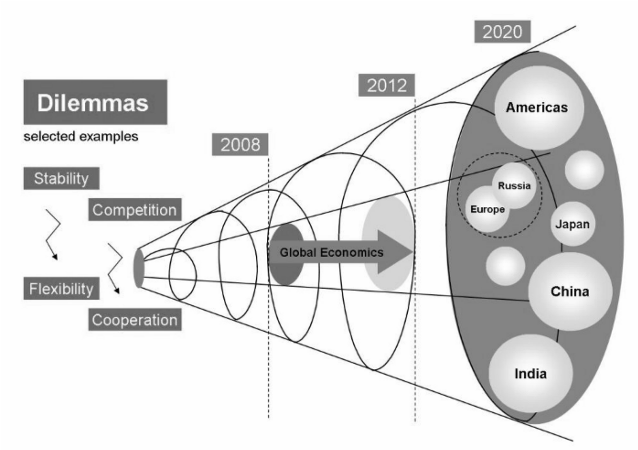

Fig. 3.1: Economic areas of the future

2 The Future is Coming – Generation 2020

2.1 Working 2020 – How will we Work in the Future?

Only unique enterprises in Germany are able to export worldwide

The development, communication and retention of **unique factors of an enterprise are the core of innovation for new processes and products**. Intersectoral cooperations contribute to the definition of uniqueness and, moreover, they can recreate new milieus of innovation trough the use of learning aptitude of inter-organizational relations.

In Germany, we can find such milieus of innovation in a unique way by looking at the **owner managed companies**, especially in the subcontracted supply of the automotive, mechanical and plant engineering sectors (REMPP 2007).

Internal and external mobility become the crucial competitive factor

Mobility and transport always refer to individuals, goods and information. However, the means of transportation are broadening. Mobility does not only occur on rails, roads, on waterways and in the air – even data and main supply increases quickly. **The importance of mobility of employees, border-crossing cooperation and the reduction of language barriers will increase against the background of the European processes of enhancement** (MICIC 2007).

Nomadic working people will displace lifelong jobholders

Aside from occupational mobility, employees in Germany are also characterized by an ongoing flexibility. Self-employment, freelanced project work, temporary unemployment: **Due to new types of employment and fixed-term jobs, the "job for life" will become an exception and the secondary job alongside part-time employment will be standard.** Many employees will increasingly become nomadic working people, multiple jobbers or mini jobbers, as well as precarious employees. However, precarious employment is hazardous against the background of the idea of life-financing full-time work. Without the association "employment means security", it is simply normal (OPASCHOWSKI 2006, LUCZAK et al. 1996; GORZ 2000, BRÜHL & KEICHER 2007).

Germany needs knowledge management for innovations

Education and knowledge are Germany's essential location economies and the very factors of production that cannot truly be imitated by others. Therefore, knowledge management is a strategic factor of success for the location Germany. In this context, a crucial point is to share knowledge in certain phases and be creative in global networks at the same time. **A balance between the poles "sharing knowledge" and "hiding knowledge" has to be found** (HENNING et al. 2006a, FORZI et al. 2003), (Fig. 3.2).

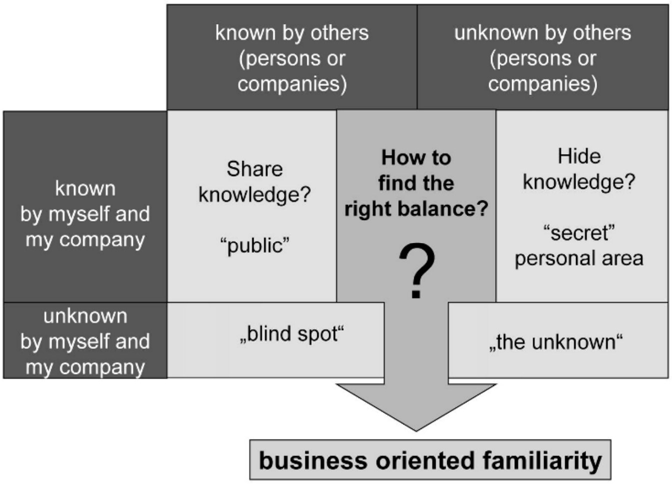

Fig. 3.2: Functional familiarity (HENNING et al. 2006b)

Out of this, a dynamic of innovation a **Business oriented Familiarity** develops. Developing this in enterprises and working processes can be done with the systematic change management method (WWW.OSTO.DE).

2.2 Learning 2020 – How will we Learn in the Future?

Learning in the process of working – a normal case for employees and enterprises

The learning culture of an enterprise is an essential factor for its competitiveness. **Learning has to be increasingly integrated in the process of working to advance the competencies of the employees as a source of innovation.** Learning on the job therefore reduces the effort of transfer in the everyday working life and stands out because it orients itself to the real processes of change. It is also integrated into these processes and uses the corresponding potentials. In this context, employees and executives develop their competencies relating to the particular potential, problem or situation. However, this presupposes not only the further design of existing types of work and learning arrangements, but also demands the establishment of skill-supporting cultures of learning and social relationships in a more comprehensive way. Against this background, further efforts are necessary to enable new learning situations on the job (REUTHER et al. 2006).

Relearning as a lifelong professional development

The acceleration of the increasing of know-how and the social processes of change requires a continuous development of competencies. Self-directed processes of learning thereby receive a stronger weighting. Regarding living and learning, the individual of the future has to become active in an entrepreneurial way. Personal key skills (i.e., the ability of self-organization, creativity, emotional stability) have to reach the same level of valuation as professional qualification. Based on the demographic change of a "society of long life", the necessity of lifelong learning is going to be amplified. For this reason, strategies of further education have to be structured in a way that also allows the educationally disadvantaged persons to broaden their competencies. Hence, forms of learning must offer different forms of access for a wide range of target groups (OPASCHOWSKI 2006).

How fast can you *un*learn

The expiration time of knowledge becomes increasingly shorter. Therefore, individuals not only have to practice learning, but also unlearning. **Unlearning provides new energy that leads to the expansion of creativity and therefore to new knowledge.** Basically, advancement consists of the capacity to unlearn, a skill that obtains increasingly less attention in the management and is not imparted by our present education system. To acquire old and learn new knowledge and to permanently look for new solutions should therefore be essential attributes of modern business management. However, unlearning should not be put on the same level as the erasing of computer data; rather, it means the production of new significances. In systems, apart from the balance, constant unlearning is the precondition to create new structures and to ensure the survivability. **Therefore, unlearning also means acceptance of chaos and imbalance,** because a balanced system is basically not in need of new knowledge to describe its status (NEUENDORFF et al. 2007).

2.3 Development of competencies 2020 – How can we keep the innovation ability in the future?

Dramatic fusions of technology enforce new ways of developing competencies for innovation

A new culture of integrated learning, working and providing requires appropriate technologies. **The dramatic fusions of technology enforce new ways of developing competencies to create innovations and the dematerialization of technique brings new chances for innovations through integrated working and learning.** In this process, the dimension of expected fusions of technologies – e.g., in the contradictory contexts between the variety of composition, material selection particularly in polymer materials, integration of nano-materials or materials with integrated smart computer devices – can hardly be overrated (MICIC 2007).

Without "older people" the change to more innovation in Germany cannot be made

The demographic change points at the need to use the potential of older people appropriately. New models can bring a balance between the diverse requirements and possibilities of the participants. **The process of aging is therefore seen as a perspective of organization for the internal politics of the development of competencies.** Analyzing the correlations between aging, health and development of competencies is an essential research and activity field.

Furthermore, the organization of the transfer of know-how to young employees receives an increasingly more important role. Even here, the growing together of the fields of learning and working becomes evident. Through appropriate methods and instruments, the potential of old and young employees has to be used and at the same time be made useful for the development of competencies of all parties (LUCZAK & STEMANN 2004).

3 How Can We Prepare Ourselves?

With respect to this background, from the point of the national level, an objective must be for Germany to obtain a steering role inside the European Union. The function of Germany as one of the economic and innovation drivers of the European Union and the world market has to be maintained. What can Germany do to make this happen?

This can only happen if knowledge, in the areas in which Germany is traditionally strong, is generated and transferred in much quicker cycles into products as well as services. The scientific focus will lie primarily on machine and plant manufacturing, the automotive industry, energy management and electrotechnology (GLEICH et al. 2006). In this regard, the developmental dynamics of the owner-managed companies in Germany are essential; these companies provide over 75% of all jobs, and most of them are small and medium-sized companies (INSTITUT FÜR MITTELSTANDSFORSCHUNG 2006). This calls for the understanding that knowledge in and out of these parts is the essential factor of production and growth with which Germany can stay competitive (DASSEN-HOUSEN 2000).

The purely quantitative definition of the EU does not only underlie the description of small and medium-sized companies, it also contains specific attributes: Small and medium-sized companies are characterized by

- the unity of risk and administration,
- the unity of independence of choice as well as the bearing of responsibility,
- the unity of economic existence of the owner and the existence of the company.

These companies especially stand for the perception of social responsibility for the employees, for the successful integration of working and learning processes and for the connection with the location of Germany. If you now ask how and where these processes are realized and what the formula of success for the creativity and innovation at the location of Germany actually is, you cannot easily ignore the owner managed companies, which are so typical for Germany.

The topic of innovation and creativity mainly depends on how the corporate elite are dealt with – these humans who, with their (micro-) enterprises, form the business location and who constantly have to find answers to the challenges in the context of working, learning and developing competencies (Fig. 3.3) (HENNING & STRINA 2003).

These elite are affected by the following behavioral characteristics:

- They think and plan in global structures and know the strengths of the regional innovative milieus (HUNECKE 2003).
- They know that the future is shaped by dynamic biographies and constant re-learning will be the normal case.
- Also generated through the I&K Technologies, the parts of working, learning and all other parts of life extend to one another. Multi-jobs will become the rule.

- Finally, multicultural competencies will increasingly affect working and learning in teams (HENNING & ISENHARDT 1997).

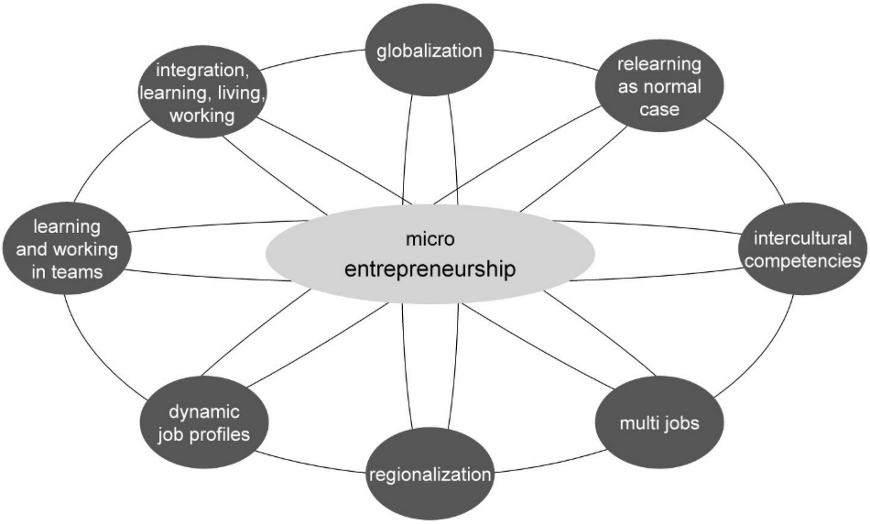

Fig. 3.3: Micro-enterprises in the turbulent environment

In the global future markets, only those companies that affect the process of innovation effectively through the micro-enterprises and focus on the process of these products and services in which we are already the world market leader at the location of Germany will be successful, following the principle: Strengthen strengths. Such companies are thereby not only characterized by their ability to identify innovation potential in early stages, but they are also able to realize and use potentials systematically. The interaction between innovation management and competition is known by many companies. However, there are immense and unused potentials in the constitution of the innovation management. While some companies intuitively incorporate this context into their entrepreneurial skills others choose the way of total standardization of their innovation process. Often, the strategic direction of an important and well-categorized process of innovation does not only define the action, but also the daily stress and the limitations of resources (STRINA & URIBE 2003).

This dilemma is the starting point and the challenge of scientific investigations in this field: To identify the worldwide practices of innovation processes that can reach the best possible results.

4 International Monitoring – How to Achieve (Global) Competitiveness in Innovation Processes?

A large research project, International Monitoring – IMO, sponsored by the German Federal Ministry of Education and Research for the research program “Working – Learning – Developing Competencies; Potential for Innovation in a Modern Working Environment” concentrates on this point and focuses on the three objectives mentioned below including the corresponding fields of action (Fig. 3.4).

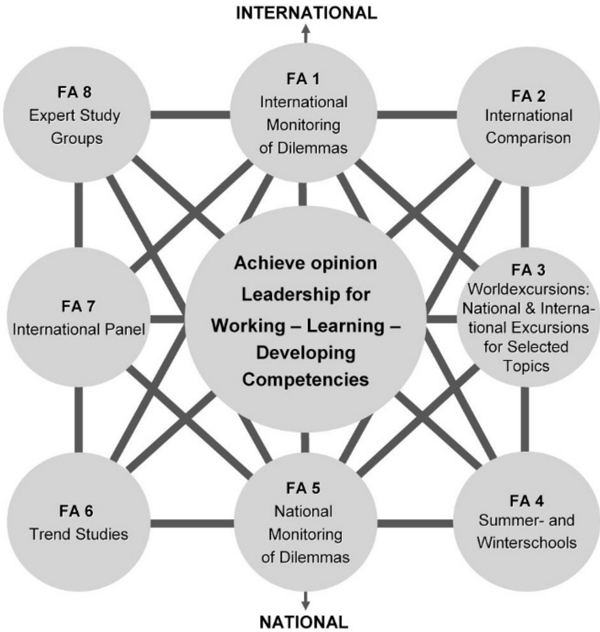

Fig. 3.4: Fields of Action (FA) of the International Monitoring for Best Practice of Innovation Processes

4.1 Continuous Acquisition and Evaluation of National and International Trends of Working, Learning and Innovation Research – Methods and Results

In the field of actions titled *International Monitoring of Dilemmas (FA 1) and National Monitoring of Dilemmas (FA 5)*, the existing and future trends will be identified and evaluated in half-yearly survey periods in the form of a Delphi study (cf. www.futureofworkandlearning.com). Based on the survey results, an early warning system to promptly identify new trends was developed for the target groups of the political, scientific and economic sector. In the long run, an accreditation and certification of international Best Practice innovation processes is planned.

On the basis of constantly occurring trend workshops with national and international outstanding experts of universities, companies and intermediary organizations, research gaps will be shown in the subject area "Working – Learning – Developing Competencies; Potential for Innovation in a Modern Working Environment" in the framework of the *Trend Studies (FA 6)*. Aside from the workshop, trend studies by participating experts will constantly be developed, e.g., "Homo Zappiens and its consequences for learning, working and social life" by Prof. Dr. Wim Veen. These are available on the project homepage:
www.internationalmonitoring.com.

4.2 Identification and Activation of Best Practice Methods for the Reduction of Dilemmas – Methods and Results

In the field of action *Best Practice (FA 2),* with the help of different national and international practitioners a criteria catalogue for the identification of Best Practice Solutions in the subject area "Working – Learning – Developing competencies" will be developed, validated and constantly verified.

Half-yearly *Excursions (FA 3)* to companies around the globe ensure the exemplification and internalization of used Best Practice Solutions. In the context of the excursions, through topic-centered workshops with the participants and companies, courses of action will be deduced for the political, economic and scientific target groups in Germany.

The first national excursion to FESTO took place in July, 2008. Main topics were the "Theory of Constraints" and the "Managements of Competencies" of the FESTO company. Within the scope of the international excursions, the companies Unichimtec (Russia) in the year 2008 and Tata Motors in the year 2009 will be visited.

4.3 Ensuring Transfer Results for the Political, Economic and Scientific Target Groups – Methods and Results

The main focus of the action fields *International Panel (FA 7), Expert Study Groups (FA 8)* and *Summer and Winter School (FA 4)* of the International Monitoring research project is the placement and transfer of results. In the framework of half-yearly occurring international Expert Study Groups for the political, economic and scientific target groups, topic oriented summer and winter schools for young professionals and researchers and four spin-off Expert Study Groups, a continuous exchange and critical discourse with questions about the constitution of a modern working environment will be established.

The first meeting of the International Panel took place in May 2008 in Berlin. The first results concerning the strengths, weaknesses, opportunities and threats of the German innovation research are available online at: www.internationalmonitoring.com.

The first congress of the Expert Study Group happened to also be in May 2008. Four national spin-offs could be founded, so the different Expert Groups will be working on the following topics: “Intellectual Capital”, “Organization Oriented to Competence of Working Systems”, “Change of Work” and “Management of the Uncertainty”.

The first summer school worked on the topic “Homo Sapiens vs. Homo Zappiens” in August 2008 in Aix-la-Chapelle. In the winter school the focus is on “Intercultural Cooperation” and will be carried out in February 2009.

Simultaneously, the results of the research project will be continuously, within the fields of action, validated and verified.

Via constant editing of the intermediate results and the deduction of recommendations based on the eight interdependent fields of action, International Monitoring has the objective to enhance, step-by-step, the basis for decision of actors in the field of political and corporate constitutions in the perspective 2020.

5 Conclusion

Because of turbulent markets, international processes, continuously made adjustments and further developments, companies in Germany are increasingly faced with global challenges. These alterations require an increased flexibility and ability for innovation by the companies and their employees in order to position themselves proactively in the international competition under the perspective of the future scenarios of 2020. Thus, the outstanding position in the world market in many fields of business should be enlarged and preserved (e.g., mechanical engineering, plant engineering and construction, power engineering and electrical engineering). The owner-managed companies, which provide more than 75% of all working places in Germany, play a significant role here for the location of Germany. The development of competitive advantages through a company and sector-specific innovation ability can be achieved with the help of relevant strategies in the fields of action of working and learning, but also in the development of organization and competencies, looking at the background of a company. Precarious employment relationships and the demographic change, relearning and unlearning in the process of work as well as continuing fusions of technologies are only a few framework requirements of the present and of the future that companies and science will have to face. In the framework of the International Monitoring project, these changes and processes will be analyzed and realized with methods of resolution and recommendations. Sustainable monitoring instruments will identify Best Practice of Innovation Processes on a worldwide basis. Thereby, the research activities in the field of working, learning and competence development will be regularly adapted to the worldwide identified tendencies. This will help to enable Germany to stay one of the worldwide "innovation champions" in the long run.

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4 The Convergence Theory and the Good ICT Society – Trends and Visions

Gunilla Bradley

1 Introduction

The area of Information and Communication Technology (ICT) and its interaction with social changes on organizational, individual and societal levels has, in the 21st Century attracted increasing attention, due to the depth and wide use of ICT. The focus on the ICT related disciplines has focused far too much on the "technology push" in contrast to human needs and requirements of the development, introduction and use of ICT. This was also the reason, when organising and chairing the Fourth ODAM conference (Organisational Design and Management) in Stockholm in 1994, that this author gave the conference the subtitle – "Development, Introduction and Use of New Technology – Challenges for Human Organisation and Human Resource Development in a Changing World". This was an event at which I received the sincere support of Professor Holger Luczak, followed by many interesting discussions at international events. He was also very supportive and generous to my extended family. It is thus a great privilege to contribute to this Festschrift in honor of Professor Luczak.

This chapter presents ongoing social changes related to the use of ICT. They are analysed under the headings: Workforce Structure, Organisational Design and Structure, Psychosocial Communication, and Work Content. A theoretical model entitled "The Convergence theory on ICT and Psychosocial Life Environment" is described, which reflects the main ongoing processes in the Net work society encompassing various spheres of life, environments, and human roles. In relation to the convergence model allocation issues, individual reactions, social informatics as a discipline, and reflections on methodology are discussed. Special attention is devoted to the individual level and humans. Concluding remarks deal with visions and actions for the good ICT society.

In this growing research field there is an increasing number of scientific journals and international conferences, and the speed of R&D and the associated publications make it very hard to get an overview. There is a risk that the research

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becomes fragmented in the strivings to make breakthroughs and in the search for scientific niches. This author tries to synthesize the present knowledge of the social and psychosocial changes in the ICT society with focus on the industrialised world.

This article is mainly based on some key note addresses that the author has held during the last few years – at the following conferences: IFIP (International Federation of Information Processing), ODAM (Human Factors in Organisational Design and Management), CIRN (Community Informatics Research Network), IADIS (International Association for Development of the Information Society).

2 Ongoing Social Changes in the Work Life in the "Net Era"

Changes related to the use of ICT are occurring in workforce structure, the structure and design of organization, communication patterns, work content/work tasks, management, and the relation between work, private and public life. The results below are primarily derived from our research over the years starting in 1974 in the developed countries.

2.1 Workforce Structure

More and more organic organizational structures spring up with a focus on flexible work processes, including dynamic networks for capital and human resources, often summarized under the concept of network organizations. Economic systems are being created where the present boundaries are increasingly becoming eroded.

So called flexible companies are becoming frequent in the present "Net Era". There is a core workforce, which consists of permanent full-time employees. They enjoy a wide range of employment rights and benefits. In the flexible company the *core workforce is decreasing*. However the other part, the *peripheral workforce, is growing*. It consists of part-time staff, self-employed consultants, sub-contracted and outsourced workers, as well as temporary and agency employees. Some of the knowledge workers are key resources, while others can easily be replaced. This is not due to competence, but rather to the applied rules for hiring staff. They might have very strong positions in the company through the network organizational structure, based on their expertise or social contacts. This phenomenon is invisible. Power is disguised in these new forms of organizations: power has no outward manifestation and is not reflected to the same extent as before in properties and belongings associated with leadership.

2.2 Organisational Design and Structure

Traditional organizational structures have a ‘military’ form illustrated with boxes and directed arrows in tree-like shapes showing the chain of command, responsibility etc. Bureaucracy was originally meant to support and protect the rights of the individual, but has developed to function in the opposite direction. These organizations still exist, but they are complemented by and sometimes replaced by network organizational structures. A metaphor of a crocheted bed cover or a table cloth can be used for describing some functions. The loops in the fabric are the individual computers of the present organizational units and all the computers are connected through the same yarn (network, tele technology). The future structure of the world – social systems, organizations, official authorities, NGOs have this basic form, even if the pattern might differ. The networks interact more and more *wirelessly.* In these networks *power and influence* can both be centralized and decentralized – coordination can both be facilitated and become harder when strong subgroups communicate and act independently. The process of building up power is invisible, as it takes place in cyberspace. Industrialization and industrial technology during the mainframe period of the computerization era were fading away along with the *hierarchical structures* of companies.

We concluded in early studies of the use of knowledge based systems (KBS) or use of applied AI that the *distribution of power* became possible in quite a deep sense (BRADLEY & HOLM 1991). Competence was being transferred to the periphery, out to the lower levels of the organisations and even to people’s homes. The present trend towards the flattening of hierarchies can also be explained due to the fact that the hierarchical regulation and control are built into information and communication systems. The trend that technology used in work life, both in the production industry and service industry, had led to increased alienation that was interrupted, by new empirical findings.

Characteristics of the network organizations are as follows: Direct communication between the various levels of the organization is applied more and more. Barriers between organizational units that deal with on the one hand the development of ideas, and on the other hand the execution of those ideas are disappearing. Power is relocated in the organization, also internationally – headquarters as well as production units are moved. The permanent changes of the organizational structure and the professional roles are partly due to and result in an increased openness and awareness of the surrounding world. New professional cultures are being developed and often complemented by being part of virtual cultures. The latter are entitled virtual communities and web based communities (WBC), and are new forms of collaboration. More and more individuals function as self-governing company units, with new challenges.

2.3 Psychosocial Communication

In network based organizational structures *psychosocial communication* has come to focus. The communication circle on psychosocial communication and technology described in BRADLEY (1977) and further developed in BRADLEY (2006), illustrates how ICT directly and indirectly affect qualitative and quantitative aspects of communication between people. One example: Leadership is directly affected by the use of ICT as a tool with several software programs for business information, decision making, communication and management. In addition the role of leaders is changing to become more like coaches to employees who have more ICT support in their professional roles. The changing leadership role is affecting the communication pattern. Finally ICT has a direct effect on communication. One part of the present ICT technology – the communication technology – plays a more dominant role in the convergence process, through internet and web. The impact and interaction with communication is valid for many aspects – structure, quality, quantity and content of communication.

When people are working more and more from their computers, greater demands are made on the social and emotional components of communication (BRADLEY et al. 1993). This is even more valid in the Net Era when people are "working together when being apart" (JANSSON 2005) as well as "being together when being apart". Working in varied environments internationally is a common work pattern. A new sub discipline in Informatics is appearing, which brings together knowledge in the field both in the developed and the developing world – Community Informatics.

An environment where people trust each other, have a feeling that they belong together and are part of a group, are aware of each other's competences, and where the communication is open and frequent, will have a much higher chance of sustainability. To be able to achieve such communication cultures, different areas in the communication circle have to be considered. Action strategies on how to handle distance and how to design the psychosocial work concern different sectors in the communication's circle which deal with various parts of the objective and subjective (perceived) work environment: Organizational structure, power structure, leadership and time management, a reward system that supports the building of an environment that is both motivating and comfortable to work in, team composition, the organizational design of a project, the content of the work tasks and the communication patterns; Physical Environment; Distance per se (JANSSON & BRADLEY 2004, JANSSON 2005). Many of these aspects were dealt with in collaborative bodies between trade unions and employer's organizations according to the so-called Swedish model. There is a need for international rethinking in the present stage of technology development of how to analyze these new work environments. Dismantlement of the systems has taken place and bodies which deal with work environment and new forms have to be established to balance capital and human well-being.

2.4 Work Content

Accelerated changes at work and in work task content are occurring in the Net Era. We have achieved more *flexible work processes* regarding both the professional role and in leadership. All human roles; professional role, the learning role and the role of citizen are becoming more and more *integrated.* Changes that dominated for many years in industry as well as in the office e.g. repetitive jobs, physically strenuous jobs, including routine work, are disappearing and a total upgrading of qualifications takes place. As a consequence the organizations became flattened out, even if we still can see organizations that maintain levels not required by company goals. *The same type of software programs* are sold and applied world wide, hence the work tasks are carried out in an increasingly similar way. This facilitates mobility in the labour market.

Our studies of young IT people in the city centre of Stockholm show that they have *strong social networks* that play an important role in their work situations. Workmates are often friends and *trust* plays an important role (in recruiting new personnel). Work tasks should have a *meaning to* their life. Most people are deeply involved in their work and find their work tasks *fun, stimulating, interesting and independent. Flexibility concerning time and space* is a key aspect in their work situation. Due to a great deal of responsibility in both work and in their private lives they feel a great freedom. They are taking care of their professional *development* – learning being a part of daily work (DANIELSSON 2002, 2007).

3 The Convergence Theory on ICT and the Psychosocial Life Environment – and Some Future Trends

3.1 Convergence Theory

The convergence model on “ICT and the Psychosocial Life Environment” is a graphical illustration of ongoing changes in the Net Society. It is presented in detail in my book BRADLEY (2006) (Some comments to the model in Fig. 4.1 will follow and the description is structured with reference to concepts in the outer circle in the figure).

The present Network period is very much based on the convergence and integration of three main technologies; computer technology, tele-technology and media technology. The convergence process (see Fig. 4.1) is enforced all the time by smaller, cheaper, and more powerful components. ICT is increasingly being used in almost every activity and embedded in more and more things (ubiquitous computing). Converging circles graphically reflect the ongoing process.

Both Convergence and Interactions are important features in the model. Convergence here means a move towards a common content. Interaction means that technology interacts with the social world with values and beliefs. There is also an ongoing interaction between the "clusters of circles". There are four levels of analysis – individual, organizational, community, and societal.

In the following, the main constituents of the convergence theory in Fig. 4.1 are presented.

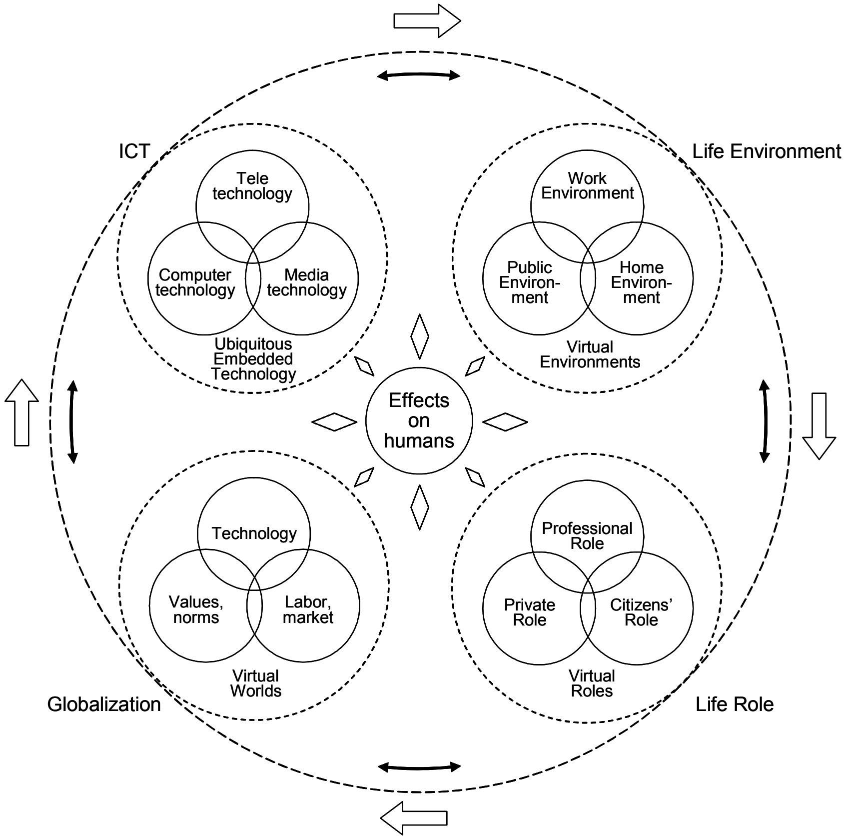

Fig. 4.1: Convergence Model on ICT and Psychosocial Life Environment (BRADLEY 2005, 2006)

Globalization (lower left in the circle in Fig. 4.1): A convergence is occurring between Technology, Economy, Norms/Values and Labour Market and is entitled *Globalization.* The geographical span is changing. At present our work life is mainly based on national and international trade which will become more global. Electronic commerce and electronic market places are creating a strong change factor behind the structure of work life. The geographical space in the future is both global and beyond – including applications of virtual reality (VR).

ICT (upper left): A convergence of computer technology, telecommunication technology and media technology is occurring to become what is defined as ICT.

Knowledge companies and knowledge workers are increasing. In these organizations *knowledge is managed in new ways.* In the 21st Century there are multiple communication channels – word of mouth, writing, audio visual, and electronic. Meta channels, e.g. meta media of virtual reality (VR) and controlled reality environments (environments that we manipulate and manage in VR) are increasingly applied.

Life Environment (upper right): Work Environment, Home Environment and Public Environment are converging to a Life Environment, where the work and public environments move into our homes. *A new emphasis* on certain dimensions in the present psychosocial environment as well as identifying quite new *dimensions* in the psychosocial environment is important. We have to be open for unforeseen implications.

Life Role (lower right): The Professional Role, The Private Role, and Citizen's Role converge to become a Life Role. Role and role formation are central concepts in social psychology and represents a level between structures and the individual. A "role" appears where psychology and sociology meet and social psychology emphasizes the interaction between the levels of analysis. In democracies the individual *can* influence and form his/her role/roles and is not solely a victim for structures.

Effects on Humans (in the middle): In Fig. 4.1 "Effects on Humans" is represented by the circle in the middle with arrows pointing in two opposite directions as a flower or a compass card, which illustrate interactions. The individual is affected by ICT, the Life Environment with its three sub environments, the Life Role with its three sub roles, and Globalization with its three components of values, technology and labor market. However, the individual can also influence the technology, the environment, and his/her own roles and phenomena on the organizational and societal level and the new virtual reality. Complexity characterizes the society and is mirrored by the fact that effects on the *individual* become more *multi- faceted and complex.* The way humans handle their situation can roughly be categorized as either *active or passive reactions*.

Virtual Reality (VR). Virtual Reality is illustrated by four circles marked with dotted lines, surrounding the four clusters of converging circles. These circles reflect our participation in cyberspace on various levels.

To the lower left part in Fig. 4.1 we could talk about *Virtual Worlds* on the global level.

Within the concept of ICT the step taken by applied *Embedded (Pervasive, Ubiquitous) technology* make the technology less perceivable to the individual and to society as a whole.

Virtual Environments in the upper right part of Fig. 4.1 is already a common concept. Online communities and virtual communities are examples.

Virtual Human Roles in the lower right part is in a more extreme form, another person/personality that people take on e.g. avatars.

The thin double-directed arrows in the outer part of the big circle represent interaction between the clusters of circles and the broader one-directed arrows represent the main direction for the movement and the process described in the circle model. Main direction is emphasized by an increasing rate of change in society. Transferred to *actions* we can in our professional role, private role and citizen's role influence our life environment on various levels of analyses, but an awareness of the speed of change is required (see further Sect. 4).

Closely connected to the convergence model is *home and home environment, where the professional role, private role, citizen's role, and learning role converge*. During the last few years we have studied changes in society and human behavioral patterns in the use of ICT in homes and home environments in the USA, South East Asia (Singapore, Malaysia) and Japan (BRADLEY et al. 2000, BRADLEY & BRADLEY 2001, BRADLEY L 2005, DANIELSSON 2002). A general trend is that in the home many human roles are converging to *one life role* and the home is moving towards encompassing also a *virtual space as well as physical.* Driving forces are converging and embedded technologies. The home could be regarded as: An extended family center; a care center; a multimedia center; a center for democratic dialogue; a market place; a learning center; an entertainment center, all of which could be summarized with a *communication sphere.*

3.2 Convergence and Allocation Issues and Digital Divide

Despite the observable process of convergence in the ICT society there are also *counter-movements* – a process of divergence. Regions, nations and subgroups in the world work towards separation, self-government, autonomy and sometimes self selected isolation. Related to this phenomenon is the allocation issue in a broad sense. Throughout computerization it has been possible to make huge profit and the question of allocating the profits should have been a key issue at an early stage. However not until recently, even if the global economy could be foreseen, has the allocation issue come into focus for actions both at the national and global level, dealing with the balance between:

- work and leisure time
- paid citizens' services versus unpaid
- production and reproduction
- cities and rural areas
- profit between:
  - sectors within a country
  - industrialized countries
  - industrialized countries and industrially developing countries.

In the Western countries we have achieved a subdivision with one group in the work force that is “overworked” and another group that is shut out from the work-force. This is not a necessary development and there are many alternatives. However in the later years ICT is used to support the “weak” in society, people with various kinds of handicaps: linguistic, physical and intellectual. The deep and broad penetration of ICT in private life is facilitating some functions for the elderly, and making life more pleasurable for senior citizens providing they have managed to keep up with the necessary knowledge.

“The digital divide” is a descriptive and analytical term whereas “the allocation issue” (allocation of resources) is a more political term. The potential of balancing deep divides in resources is inherent in ICT, but action plans are needed – both short term and long term.

3.3 Convergence Model and the Individual Reactions

Regarding “Effects on Humans” in Fig. 4.1 we can conclude that the use of ICT has changed the following human qualities so far: identity and self-perception; social competence; creativity; integrity; trust; dependency, and vulnerability. For example the identity of humans has acquired new and additional bases through the participation in various virtual and online communities. Each of those qualities could either be strengthened or weakened.

In stress-theoretical terms we often talk about the importance of balance. ICT is contributing to a balance or an imbalance between for example: *emotional – rational components of life; female – male aspects; involvement – alienation.*

Research shows that an *accelerated tempo* is occurring in the industrialized world. There are reasons to talk about “ICT stress” or “Internet stress”. Certain ICT stress is related to the fact that we have an increased *dependency* on computers and networks and an increased expectancy that these technologies are functioning well. Stress phenomena in the Internet world are *information overload, contact overload*, demands for *availability,* lack of *organizational filters*, and difficulty in separating “noise” from essentials, changing level of expectations and an altered *perception* of time and space in general.

Tasks and environments that expose people to one of the two poles of over stimulation and under stimulation should be avoided in our society due to: the risk of stress (the individual level); the risk of a fragmented labor force (group/organisation levels); the risk for a digital divide in nation states; the risk of marginalization and exclusion from the mainstream of society (individual, group and societal levels).

The individual level needs more attention with respect to interaction between ICT – Society – Individual. There are both positive and negative impacts on the Individual. In the present flexible network organizations too much responsibility is put on the individual who loses permanent employment. The so called “peripheral work force”, often “knowledge workers” have to manage his/her competence development and market him/her, when they as individuals are exposed to a competitive world market.

This pattern could be seen as freedom from paid work in a traditional sense and freedom to choose your life. However, we all need a basic security as employees and citizens and there is a need for balance between a strong society and strong individuals. Most people are not "strong" throughout life and we need to think in terms of *sustainability* both regarding physical and social environment and thus sustainable human beings.

3.4 Convergence Theory and Social Informatics and Methodology

During the last few years a key question has been formulated by international bodies and organizations as to how the human being and their societal environment can be kept in the center and how to build up an "Information Society for All", when developing our more and more complex ICT (Information and Communication Technology) systems.

New universities sometimes entitled IT universities, are appearing in many European countries trying to bring together disciplines from the traditional universities and disciplines from the technical universities in order to facilitate a necessary rethinking and reorientation of R&D, sometimes resulting in new centers called "Humans in the ICT-society" focusing on the human, organizational, and societal aspects of ICT use. Empirical experiences show that it is important to keep a balance between, on the one hand pure technical research and development in software and hardware technologies including new fields such as nanotechnology, and on the other hand the behavioral and social science disciplines such as psychology, sociology, cultural anthropology, urban/rural planning, and ethnography.

When this author started research in the field in 1974 I considered myself to be a behavioral scientist, educated as a psychologist and working at a department of sociology, doing cross disciplinary research together with computer and system scientists, economists, sociologists. I "sailed against the wind" in the academic world but I had great support from the labor market organizations both on the employer side and employee side – these were represented in the research financing boards at that time. Thirty five years later as a Professor Emeritus, I can conclude that my research orientation is now in the front line of Computer and Systems Science and other ICT related fields. The research questions that I once raised are now in the centre of many international research programs. Social and Societal Informatics is an academic discipline per se. Most research and books from my hand were published in Swedish (some selection in the reference list). 'Psychosocial Work Environment and Computers' was the title of my first international book (BRADLEY 1986, 1989) and was widely used in computer and systems scientists and contributed to the growing discipline Social Informatics – but used as such somewhat different concepts due to my academic background. Social

Informatics is the interdisciplinary study of the design, uses and consequences of information technologies that takes into account their interaction with institutional and cultural contexts (KLING 1999).

Theories, methods, and results from the RAM (running from 1973 to 1985) were described in the book 'Computers and the Psychosocial Work Environment' (BRADLEY 1989). The RAM project analyzed three main historical periods of computerization and ICT from the main frame period with the use of batch processing systems to on line period and use of display terminals. In the book Social and Community Informatics – Humans on the Net (BRADLEY 2006) the fourth period – the network period was included and the theories developed in RAM were revisited. The methods for empirical testing of the model could equally be applied to later periods of the developments of ICT. The term "computer program" in the questions and text in the qualitative and quantitative research instruments could be substituted by ICT applications, ubiquitous technology, wireless personal communication (for example laptops and PDA's) – depending on what type of technology or combinations of technologies are in focus.

ICT again is described in the model as a convergence between computer technology, tele technology, and media technology (multimedia) and what is now entitled as ubiquitous technology (embedded, pervasive, VR). Research in the Media Technology related disciplines are often focusing on the social and societal impacts of the use of ICT. That research mostly focuses on the private and citizen's role, more seldom on the changes in the work life.

The tools for collecting and analyzing research data of various kinds can be the same and complemented and facilitated by use of ICT tools but the identification of the causal factors are much harder in the ICT society and more so when we have reason to talk about the ubiquitous society. Causality is per se problematic – most processes in the social sciences are interactions, but the present and future technology applications are invisible, and embedded in the instruments, in the environment, in the networks and the change process becomes more and more invisible.

4 Concluding Remarks – From Theory to Actions

Research on ICT, society and the individual and analyses of the associated *psychosocial processes* have led forward to address goals and visions of the ICT society. They could be formulated as *policy statements* and with positive formulations of goals to be reached. ICT should contribute to goals such as (BRADLEY 2001):

- Information access for all
- Wellbeing and quality of life for all
- *Enrichment* in the social contact between people
- Integration and respect for diversity

- Greater *autonomy* for the individual
- Prevention of various kinds of overload and stress
- Deepening of true *human qualities*
- Deepening and broadening of *democracy*
- E-cooperation and *peace*
- *Sustainability* in a broad sense, including the environment, economy, and human side.

Internationally the first official statements of goals for the ICT society were formulated at the World IT Forum (WITFOR 2003). The so called Vilnius Declaration brought forward goals which had a great implication for the involvement of the developing countries e.g. *bridging the digital divide* between rich and poor in the world; urban and rural societies; men and women; different generations. Another main concern was *reducing poverty* through the use of education and Information and Communications Technology (ICT).

Sustainability and the use of ICT are closely connected. Sustainability can be defined as a convergence between environmental, economical, social and cultural sustainability. Important perspectives are system perspective, holism, human aspects, bottom-up, common good, and equality. Many of these concepts are overlapping and possible to analyze from various angles. Action-oriented and value-oriented research is coming to the fore. Social Informatics is high-lighting a field of research, practice and education with accelerated speed of change and complexity as well as urgency. Social Informatics is more and more being a mandatory part in education and training in ICT-related disciplines. There is a need for a much stronger support internationally for cross-disciplinary, cross-cultural and action-oriented research on the topic “ICT for the Deepening of Humane and Societal Qualities”

Official bodies on the international and national level e.g WSIS (World Summit on the Information Society) and national ICT programs are actors as we move to an ICT society on a global scale. Various components of ICT such as internet, web, and blogs should be used for *dialogue between cultures*, to increase *mutual understanding*, and *enrich us* all. How can *Human Rights* be more deeply understood, exemplified and applied in the ICT society? In 2006 the United Nations started to review the issue of Human Rights – the use of ICT globally has made the need of this review clear. Visions are shared about wellbeing, democracy and quality of life for all as well as social, economical and ecological sustainability – illustrated in the convergence of circles in Fig. 4.1. We can all be *actors* in this process, researchers, IT professionals, NGOs, and an *Individual.*

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5 Community Ergonomics and Globalization: A Conceptual Model of Social Awareness

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1 Introduction

Community Ergonomics (CE) was developed from two parallel directions. One came from existing theories and principles in Human Factors/Ergonomics and Behavioral Cybernetics which have been applied to assess situations and find solutions at a macroergononic level (SMITH 1966, SMITH & KAO 1971, HENDRICK 1986, CARAYON & SMITH 2000, TAVEIRA & SMITH 2006). The second direction emerged from the careful and thorough documentation of specific case studies of communities, which in turn led to additional principles and theories with more contextual relevance (SMITH, CONWAY & SMITH 1996, SAINFORT & SMITH 1996).

Thus far, CE has been applied at the community level and some of these applications have been documented (COHEN & SMITH 1994, SMITH, COHEN, CONWAY & SMITH 1996, SMITH & SMITH 1994, SMITH et al. 2002, CARAYON et al. 2001). This chapter will examine the applicability of CE at the international level, specifically for corporations engaged in international development and trade. This will be done in two steps. First, the transferability and applicability of CE theories, principles and tools from the local community level to the more global international level of analysis will be examined. Then, CE principles (SMITH et al. 2002) will be restated so that they can be applied to the international level of analysis.

2 Background

Organizations are complex systems which have been defined in terms of their characteristics such as structure (formal and informal), culture, purpose, products and services, climate, workforce composition, leadership, management style, processes, tasks, technology, tools, image, reputation, information flow networks and mechanisms, labor-management relations, geographical context or scope

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(global, national, regional, local), societal context, and size. Organizations evolve in a dynamic environment and have technical and personnel sub-systems that interact to produce outputs. The coordination, integration and combination of these aspects of organizations need to be properly managed to provide effective and efficient operations. This is particularly true for international corporations, especially those operating in industrially developing countries (SCOTT 2008).

The world has become increasingly more open, taking organizational design principles and management practices to a new level of acceptance and application in the last half of the twentieth century and into the twenty-first century. Simultaneously, this time period has seen struggles for fairness, equality, freedom, and justice for peoples of many nations. The 2008 report by the World Health Organization on "Closing the gap in a generation: Health equity through action on the social determinants of health" clearly outlines the many complex factors that contribute to health inequities, including conditions of daily living (e.g., working conditions) and access to resources (e.g., water) (http://www.who.int/social_determinants/final_report/en/index.html). In addition, a more complex global economy has emerged throughout the world with increasing trade and commerce among nations. Accordingly, organizations have had to operate within a complex world economy characterized by the following issues, among others: continuous change, a heterogeneous (often international) workforce at all job levels, increased spatial dispersion of physical and human assets, decreased standardization, increased diversification of products and markets, decreased centralized control of resources and information, uneven distribution of resources, variable performance within and between locales, increased operational and safety standards, and increased susceptibility to global changes in the economic, social, political, and legal conditions. Those organizations can be conceptualized as complex sociotechnical systems that have many diverse interactions with their environment (CARAYON 2006). Many organizations have responded to the opportunity presented by the unique openness of the world economy by expanding production and trade worldwide.

In this climate of increased international trade, important issues of social and cultural values need to be carefully examined. Culture, in and of itself, is hard to define in a way in which all its facets and dimensions are appropriately addressed. However, there exists a common understanding and acceptance of what specific culture and cultural values mean. In terms of a global value, there seems to be a universal agreement that mutual respect and fairness are at the heart of healthy multicultural dynamics. The right to be respected requires showing respect for others and not violating this universal right. The same can be said for fairness and other considerations such as commitment and responsibility. There is a requirement to be mutually tied together so that the welfare of one party is important to other parties' interests.

There is little agreement about what makes effective multicultural organizations. This has led to the emergence of more refined international management practices in response to numerous obstacles encountered when organizations expand abroad or when they transfer processes abroad. Difficulties encountered in growth, expansion, internationalization and globalization are mainly due to the following factors: (1) the lack of a process for effective transnational transfers, (2) the lack of knowledge of operational requirements and specifications in newly entered markets, (3) ignorance of cultural norms and values in different countries, (4) the lack of adaptability mechanisms, and (5) low tolerance for uncertainty, ambiguity, change and diversity.

Much progress has been made to address some of these issues, but there are critical problems that still remain at the organizational level. One of the most important problems is the lack of a "genuine" corporate commitment to social responsibility with the same intensity as the desire for increased profits. In fact, some managers may believe that social responsibility may conflict with corporate financial goals and tactics. We believe that long term corporate stability and success (profits) follows from community support for the enterprise and its products. Social responsibility nurtures the mutual benefits for the enterprise and for the community that leads to stability.

We propose that multinational corporations must accept a form of corporate social responsibility that recognizes the universal rights of respect and fairness for all employees, neighbors, purchasers, and communities in which they operate. Whether these rights are profitable or not in the short term, or difficult to attain, such corporate social responsibility needs to be undertaken if global ventures are going to be successful in the long term. It is our belief that the survivability, acceptability, and long term success of the corporation will not only depend on profits, but also on global social responsibility. Such global social responsibility will lead to greater accessibility to worldwide markets.

Organizational structure must go beyond the microergonomic and macroergonomic levels (HENDRICK 1986) to also include the societal (or cultural) level (DERJANI-BAYEH & SMITH 2000). This will enhance the "fit" between the organization and the economic markets within which it operates. They must address multicultural design, a comfortable corporate culture, and principles of respect and fairness for employees, customers, and neighbors (CARAYON & JÄRVENPÄÄ 2001). We believe that this will improve the "fit" with the international "cultures" in which the corporation operates (DERJANI-BAYEH & SMITH 2000).

3 Transferability Criteria

The transferability and applicability of theories and principles are often not universal. This is especially so when an *ergonomic* concept of improving the "fit" is applied, since ergonomic approaches focus on the "unique" characteristics of the environment (culture) and of the person (or the organization) to get the best match.

A number of key factors may be considered transferability criteria that determine whether a set of situations are comparable. These comparability criteria are:

Content: This defines what the internal situation is. For instance community characteristics such as learned helplessness, dependency, cumulative "social" trauma (CST), poverty, deficiency in access to and appropriate use of resources affect the potential fit. Often, fundamental improvements must be made in combination before fit can be addressed.

Table 5.1: Hazards at the community and international levels of Community Ergonomics

Societal Symptom	Definition	Local or Community Level of Analysis	International Level of Analysis
CST-Cumulative Social Trauma	This is the outcome of long term exposure to detrimental societal conditions leading to a cycle of dependency and ineffective coping.	Inner cities with low quality of life, high unemployment rates, low quality of educational, health, security, and social services.	Developing countries with low quality of life, high unemployment rates, low quality of educational, health, security, and social services.
Adverse Societal Conditions	These are the specific detrimental societal conditions in the environment within which people have to function. The severity of the adverse condition determines the likelihood of survival or proper social development.	Communities with high unemployment rates, high crime records, high drug trafficking occurrence, high teenage pregnancies, low education level, low security, health care, low income, low skill level, high corruption.	Countries with high unemployment rates, high crime records, high drug trafficking occurrence, high teenage pregnancies, low education level, low security, health care, low income, low skill level, high corruption, political and economic instability.
Societal Isolation	This is the phenomenon that results from segregating, outcasting and alienating groups of people, and treating them with inequity and unfairness	Inner cities, ghettos, barrios.	Developing countries with little economic power and weak political leadership.
Societal Symptom	Definition	Local or Community Level of Analysis	International Level of Analysis
Economic Dependency	Requiring assistance from others. This is the result of needing to survive and seeking help, with no skills or mechanisms to ensure long-term improvement and growth.	Welfare systems, federal funding, unemployment programs, etc. which provide immediate assistance but no survival skills. Once down it's hard to get up.	International Monetary Fund, World Bank, international institutions lending money with high interests and restricted stipulations but no financial management or administrative leadership or knowledge.
Learned Helplessness	This is a long-term self-perception of recurrent social isolation and economic dependency that disables people from improving their lives.	Multiple generations of welfare recipients, conformity with the surrounding and observed standard of living as one's highest potential goal.	Countries that are constant recipients of loans and support leading to a perception of disability and helplessness.

Table 5.1 points out some symptom characteristic of settings where CE has been shown to be useful at the community level, and we have expanded this to show how these same symptoms are present at the international level.

- *Context*: These are conditions external to the situation itself, which are affecting or being affected by the situation. The context captures the environmental, political, social, and economic climate. The context is highly influenced by religion, social class, political, ethnic, age and gender issues, and may dominate the particular place where the situation takes place.
- *Process*: These are mechanisms describing how the personal, corporate or community situation operates. The process is defined by the mechanisms linking people or corporations to their particular environment, leading to predictable outcomes. Understanding the process is essential in pinpointing crucial points of intervention to eliminate societal hazards or to minimize the negative impact of such hazards.

These transferability criteria may be used to expand CE from the local or community level to the global or international level of analysis and application, as shown in Table 5.1.

4 Community Ergonomics Principles in an International and Multicultural Context

The principles focus on the goals of social responsibility, fairness and social justice, and do not threaten the prosperity of a company or organization. They are built on the premise that the society and communities in which a corporation operates and from which the corporation generates profits should benefit from the presence of the company. Thus, the corporation should contribute to the development, growth and progress of the local communities. These principles propose a symbiotic relationship between the hosting community or "society" and the "guest" corporation.

4.1 The FIT Principle

Due to the diversity of the workforce in multinational ventures and the ongoing trends of today's world economy, accommodations need to be made by companies for a diverse workforce. That is, companies need to design for cultural diversity. Corporations must understand and incorporate the norms, customs, beliefs, traditions and modes of behavior of the local community into their everyday operations. In some communities there will be multiple cultures that need to be included in this process. Often there is a need to strike a balance among the various cultures as they are not always compatible. The corporation's organizational structure and operational style need to be flexible to bridge the gap between the corporate and local culture(s). This cultural accommodation will produce commitment to the corporation from employees, customers and neighbors.

4.2 The BALANCE Principle

The balance principle is taken from a concept proposed by SMITH and CARAYON-SAINFORT (1989) that defines the need to find the proper relationship among components of a complex system. Based on this concept we believe that there is a need for balancing corporate financial goals and objectives with societal rights and corporate social responsibility. Companies are a part of a larger community and through their employment, purchasing, civic, and charity activities they can influence community development and prosperity. As an integral part of this larger system, companies have a responsibility to promote positive balance for the benefit of the community and the corporation. Positive balance often cannot be achieved by optimizing any single or sub-set of components of a complex system. Thus, corporate profits or market share may not produce positive balance in the complex community/corporate system. Rather, the best overall system outcome may be achieved by trading short-term profit optimization for long term stability through accommodation of all elements of the system including the community.

4.3 The SHARING Principle

Traditionally, a corporation's success has been measured in terms of its financial growth. There are many factors that may lead to this financial growth including the value of the company (stock price), market share, sales, profits and assets. However, there are other factors that are not usually taken into account but will become more critical as social awareness becomes more prominent. For instance, customer loyalty, community support, and acceptability of products will be related to the corporation's long term financial success.

If a corporation chooses to invest some of its profits back into the community in ways that are significant to that community, then the corporation may be viewed not only as a business but also as a community partner. Such contributions may take the form of building schools, providing educational scholarships, providing technical training and skill development, giving assistance to small or family owned businesses, or developing community utilities. In giving something back to the community the corporation is developing loyalty to its products and protecting its long-term profitability. This expands the concept of 'healthy organizations' (MURPHY & COOPER 2000) to include the financial health of the company, the health of the workers, and the health of the community where the company is located.

4.4 The RECIPROCITY Principle

This principle deals with a process of mutual commitment, loyalty, respect, and gain among communities, corporations, employees and consumers. This principle results from the BALANCE and SHARING principles. A bond results from the corporation giving something back to the community, which builds loyalty from the consumers to the company, and eventually leads to a genuine sense of loyalty from the organization back to the community. In this respect, what might have started as responsibility, will over time become mutual loyalty and commitment. Within the corporate organization, the same phenomenon takes place when the organization shows responsibility towards its employees, who in turn become loyal and committed partners with the corporation. Happy employees and community members become loyal consumers of the corporations' products.

4.5 The SELF-REGULATION Principle

Corporations should be viewed as catalysts of self-regulation and socio-economic development in host communities. Communities and countries in disadvantaged economic conditions (see Table 5.1 above) typically show symptoms of learned helplessness, dependency, isolation and cumulative social trauma. Instead of perpetuating conditions that weaken people and institutions, an effort should be made to help people to self regulate, grow, flourish and become productive. In this effort, corporations are very important because they provide employment, training, and professional development opportunities that give people the tools to help themselves. Corporations can also invest in the community infrastructure, such as schools, clinics, and hospitals, which produces stronger, healthier and more independent communities for the future.

Through community ergonomics, corporations can help disadvantaged people understand that they have the right to a better, healthier, more productive life. The self-regulation principle asserts that it is in the self-interest of those who have economic privileges and resources to share them with those who do not. For such sharing should produce prosperity and self-regulation, and less need for future sharing. It brings about stability.

4.6 The SOCIAL TRACKING Principle

Awareness of the environment, institutional processes, and social interaction is necessary for people and corporations to navigate through their daily lives, and for communities to fit into the broader world. Awareness helps to control the external world and leads to a more robust, flexible, and open corporation/community system design. It is important for community members, employees, and corporations to be aware of their surroundings to be able to predict potential outcomes of actions taken. In particular, it is important for corporations to develop a certain level of awareness regarding the workforce, the community, and the social, economic and political environment within which they operate. This includes the cultural values of the people affected by the corporation's presence in a particular community. When we consider that change is a normal aspect of the global economic arena, it is critical for effective decision making to track change and to understand the implications for the corporate/community system.

4.7 The HUMAN-RIGHTS Principle

This principle underscores the belief that every individual has the right to respect, a reasonable quality of life, fair treatment, a safe environment, cultural identity, respect and dignity. Everyone should be able to breathe fresh air, preserve their natural resources, achieve a comfortable standard of living, feel safe and dignified while working, and be productive. The term "human rights" implies that people are entitled to these considerations. Communities and corporations should be consciously fair and righteous in achieving their economic goals and objectives. People should not be assigned a difference in worth based on class, gender, race, nationality, or age. The workplace is a good starting point to bring about fairness and justice in societies where these currently do not exist as a norm. It is left to the corporations' discretion to use their economic and political power to bring about social change where human rights are neglected.

4.8 The PARTNERSHIP Principle

This principle proposes a partnership among the key players in the system in order to achieve the best possible solution: corporation, community, government, employees, and international links. By doing this, balance may be achieved between the interests of all parties involved, and everyone is treated fairly. In addition, partnership assures commitment to common objectives and goals.

5 Conclusion

Operating a business beyond traditional boundaries and entering other cultures and societies should be undertaken with sensitivity for the needs of the new communities. The essence of successful internationalization, globalization and multiculturalism is in the culture and climate that the corporation develops. This corporate culture needs to be sensitive to the communities and the population diversity of the many locales where the corporation operates. This includes respect, partnership, reciprocity, and social corporate responsibility towards employees, community, customers and society as a whole. It requires seeking a balance between the corporate culture and that of the community where the business operates and the cultures brought into the company by the diverse employees. In the past, corporations have entered new markets all over the world, profiting from cheap labor, and operating freely with little or no safety or environmental liability. However, the level of social awareness has increased all- over the world, exposing sweat shops, inhumane work conditions, labor exploitation, and environmental violations across the board. Today corporations need to be doing business with a “social” conscience. By doing this, corporations will become welcome in many part of the world, and their products will be sought out and accepted. Consumers, employees, governments, communities and societies will be support of such businesses. The key to international business success is not in just being financially shrewd, but also in balancing economics with social awareness and social corporate responsibility.

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6 "Car Mechatronic"– An Open Approach for Designing a New European Core Occupational Profile

Georg Spöttl

1 Introduction

The European automotive service sector is dominated by global acting car producers which produce cars at a high level of quality. But developing respective qualifications and competences for servicing cars is the objective of technical education and vocational training systems (TEVT) in Europe which are different in terms of historical roots and their institutions and organizational structure.

The predominant contradiction of this situation is that the product – the car – is produced at a high quality by all manufacturers whereas highly differentiated TEVT-systems result in great differences of the development of qualifications and competences and their quality. This contradiction – the high quality of cars and the highly differentiated TEVT-systems with their heterogeneous quality – formed the background for a long-term research work and the accreditation of the (first) European Core Occupational Profile – the Car Mechatronic (The term "Car Mechatronic" is not only used for the integration of electrical and mechanical systems. This term means more than the concentration on technological systems within education and training processes. The term is based on the philosophy of a holistic curriculum concept going along the work process. It also includes the car "as an entity" with all technical and social requirements.). The research work and discussion started in the early 1990s and was carried on until today. The surveys concentrated on the changes in the automotive service sector, on the changes of work tasks, on work organization, on technological challenges, on qualification concepts and on service philosophies of various car manufacturers in different countries.

The second period of the discussion started in 1998 and was dominated by the Social Dialogue within the entire car service sector. During this phase emphasis was given to the development of an occupational profile within the framework of

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the LEONARDO DA VINVI programme and its accreditation in partner countries. The process was accompanied by a national and European Social Dialogue aiming at making the European Occupational Profile acceptable for national framework conditions. A European and a World Automotive Congress as well as a number of workshops on the accreditation of a European Occupational Profile supported this process.

The first step in the development process was based on a research commission within the framework of a FORCE programme carried through by the Institut Technik & Bildung of the University of Bremen (The author was project coordinator of this research project and of the subsequent LEONARDO projects.). It was the beginning of a manifold research work in different European countries.

After just one year of research work, the sector and company oriented surveys already revealed a considerable discrepancy between the existing Occupational Profiles and the corporate requirements in most countries. The existing Occupational Profiles are oriented towards technical-scientific contents whereas the enterprises request process competence, the ability for problem solving and a high identification with the tasks. In spite of the participation and even the dominance of the Social Partners during the creation of Occupational Profiles in many countries it was not always possible to convince planners of vocational educational processes to overcome the technical-scientific way of education in favour of a process-oriented competence development.

A lot of questions about the reasons for this contradiction and its resolution by all persons involved still remain. Based on the research in the automotive service sector a European oriented occupational profile will be described which – supported by a European dialogue on vocational education – may contribute to a practice oriented competence development by preserving the national educational objectives. The European economy would draw benefits from this development as Europe oriented occupational profiles are likely to ensure a high qualification level in all European countries (HESS & SPÖTTL 2008).

The comprehensive research process for the identification of sector developments by a so far not yet applied research method will be briefly described in Chap. 2. The role of the social partners who accompanied the research process will be highlighted. Chapter 3 concentrates on two focal points. The new challenges for the automotive car service sector will be shown and the necessity to train all-round technicians. A work process oriented curriculum structure will be developed in Chap. 4. The core characteristics of the curriculum structure and its development will be explained. Chapter 5 will clarify the conceptual initiatives taken to implement the occupational profile in European countries with a special focus on the Social Dialogue.

2 A Research Approach to Identify Changes of Work and Future Oriented Needs of the Industry

The main objective of the FORCE study was to compile knowledge on situations and practices in the development of selected sectors as well as in the field of (continuing) vocational training (CVT) in the European Member States. According to the Maastricht Treaties this knowledge should promote the development towards an exchange of information and experiences with regard to common issues of the educational systems of the EU Member States (Art. 127) and thus facilitate the implementation of a continuing vocational training policy as an answer to the need for qualification.

The construction of an adequate "image" of the situation within the automotive sector in Europe – as it was required from the study – made high demands to the descriptive quality of the survey and the documentation of the situation in its complexity. This approach clearly differs from scientific traditions of hypothesis-guided research. The FORCE committee set limits to the research framework. A comparative description of the situation within the automotive sectors of EU countries was demanded while clearly limiting, however, the appraisal of the differences. "Best practice" and "normal practice" were to be highlighted. An assessment of "bad practice" should not be envisaged (RAUNER & SPÖTTL 1997).

The most important discussion topics of the 14 participating research institutes were how to carry through an international comparative survey within this framework in the automotive sector concentrating on the interrelation of the change of tasks and vocational education and how to identify further issues for a European vocational educational research. The results of these considerations cannot be laid down in detail here. The essay concentrates on sketching the eventually chosen path (BECKER & SPÖTTL 2008, SPÖTTL & BECKER 2008).

Apart from general sector specific surveys in 12 countries, case studies were carried through in enterprises all over Europe. The enterprise is the focal point for case studies and permitted to probe into vocational education by studying the context of corporate development (organization, changes of tasks) and to link it to the technological changes. In terms of methodology, there is a slight blurredness which hampers the comparison of the thus defined cases due to country specific traditions and regulations for the foundation of enterprises and the corporate processes. The enterprise as the focal point can prevent one of the most common prejudice of vocational education, i.e. the "new contents of qualification are derived from" new technologies (RAUNER & SPÖTTL 1995).

The automotive study is marked by three methodological characterizations:

(1) The methodological concept of 50 case studies as well as 12 sector studies (in 12 member states) aimed at reaching a special qualitative representation.
(2) A second methodological feature of the sector studies is the close relationship between the research process and the Social Dialogue. It could even be said that the sector studies owe their importance to this relationship high-

lighting elements of research on actions. A great number of misunderstandings and conflicts between the participating enterprises, institutions, and scientists on the respective role in the interplay between research and Social Dialogue show that concepts and experiences of a research on actions may be taken advantage of. A methodological approach must, however, be developed which is oriented towards the specific characteristics of an international comparison.

(3) The third characteristic is based on the decision of the FORCE committee not to carry through the sector studies as evaluation projects and to highlight only "best" and "normal" practice. This means a certain limitation for research. At the same time, however, this approach calls for the development of an evaluation concept. Due to the fact that the European vocational educational science had so far not developed any of the required instruments the integration of the Social Dialogue into the research process came as a logic consequence.

The research work within the studies resulted in deep insights into the development and implication of the service sector in terms of changes in work organization, technological requirements, ecological regulations and so on. It was above all the participation of the social partners and selected sector experts in the discussion of the results which contributed to a clear outline and which paved the way for the development of occupational profiles.

3 Changes of Work in the Automotive Service Sector

3.1 Overview of Changes

The modern car service station is witnessing many and diverse changes of tasks. Challenges essentially result from four factors:

- from the higher safety demands and standards;
- from the decisive market criterion of quality service combined with the lowest possible level of repairs;
- from legal stipulations in the field of environmental protection, traffic safety and consumer protection;
- from the desire to "individualize" one's car by means of special accessories.

The many-sided challenges for quality service within the automotive business result above all from the necessity of corporate development, the needs of the customers, the relationship between dealerships and manufacturers and the circumstances and regulations arising from the development of society and the State (RAUNER & ZEYMER 1991, SPÖTTL et al. 1997, TUITE 1994).

A quality-driven service station must meet manifold government demands by an appropriate deployment of resources, procedures and forms of organization in order to optimize skilled work and specialist advice to

- achieve a high level of customer satisfaction and
- ensure the safe and reliable operation of the vehicle in compliance with the standards and regulations in force in the traffic and transport area and the operation of a quality service station meeting all current demands.

The manufacturer is confronted with the subjective, social and business challenges and must respond with various measures. The better he meets them, the greater are his chances on the market (RAUNER 1997).

On the one hand, the manufacturer must design the characteristics of the vehicle in a way that it may be reliably operated in traffic complying with all standards and legal regulations. On the other hand, he must be able to assemble a car for the customer corresponding exactly to the latter's ideas – with regard to quality, configuration of equipment, styling, technology – but which will also to a great extent satisfy social demands, such as ecological acceptability, a high level of active and passive safety, little servicing and repairs. The quality service station is meeting these demands – with the help of the manufacturer – by providing the customer with the best advice for all situations and by giving full and proper attention to all repair tasks.

Today, the following points are essential for the car service sector:

- The requirements of the customer must be fulfilled quickly and at reasonable prices;
- The necessary time for maintenance, service and repair must be measured;
- The product itself and also the service must be of the highest quality;
- The key to success is maintaining a good customer relationship;
- A high level of cooperation and job satisfaction of all participants ensures best possible results in carrying out customers' orders;
- Competitiveness requires highest quality of service and repair work (PATZATZIS 1995, RHYS 1994, RAUNER et al. 1995).

The modern automotive service station is dominated by the highly efficient coping with tasks such as diagnosis, repair of networked cars, all-round car service, the handling of highly complex tools, flawless customer service etc. Sophisticated repair techniques for the car and its components have already lost their importance. The car service stations must rely on technicians trained as all-round technicians and able to highly efficiently cope with all tasks related to the car. The last objective can only be reached if the all-round technicians and their companies are allowed to shape their work places in a way to support a successful completion of work tasks (The US American automotive sector is the best developed sector in the world. The ASE concept (Automotive Service of Excellence) has developed standards for technicians oriented towards highest challenges. About half of a total of 2 million persons engaged in the sector fulfill these standards).

The transition from a simple repair shop to a quality service station, combined with the related reshaping of the employees' responsibilities, suggests that this development should be supported by staff training on a wide scale. Quality service demands technical qualifications in mechanics and electronics – and the integrated systems resulting thereof (The integration of mechanic and electrical components to comprehensive systems is usually called a "mechatronic system".) – and above all the ability to advise and communicate, a competence in methods, a highly developed sense of responsibility, precision, trustworthiness and quality awareness.

3.2 The Need to Redesign the Competence Structure

In the light of the structural changes it is also important to create effective instruments for the development of occupational profiles and curricula which represent innovative guidelines for the improvement of competences necessary to cope with the tasks in complex work processes. Two corner points are relevant for this process:

(1) An mere orientation of occupational profiles on technological subjects does not meet the requirements of modern work processes as well as the changes in work organization and business orientation.

(2) Curricula merely adhering to specialized and scientific systematics do not meet the requirements of the work processes and are very inflexible when it comes to cope with the rapid changes witnessed by the industry. The mentioned systematics do not represent a beneficial backbone for the support of a practice oriented vocational training and education. New strategies have to be developed as an answer of the vocational systems to the swift changes in Europe's industry (SPÖTTL 1999).

The main idea behind innovative educational concepts is to place the business and work processes of the car service center and the "car as an entity" in the center of educational planning. The linking of operational processes and vocational training facilitates a dynamic and open educational planning. Parameters like, for example, size and orientation of the firm or regional characteristics can be taken into consideration.

Therefore it is advizable to realize a holistic training programme at skilled worker level. No new specialist occupation is being created here but rather a comprehensive occupational profile is proposed which seems suited to promote the development of repair shops towards quality service stations and to increase the flexibility of employees in the European employment market.

4 The “Car Mechatronic” Concept – Occupational Profile and Curriculum Structure

4.1 Framework of the Occupational Profile

The idea of a European occupational profile of a “Car Mechatronic” was an outcome of the studies carried through in the car service sector (Project partners were: Dublin Institute of Technology (IRL), IG-Metall (D), Instituut voor Toegepaste Social Wetenschappen – ITS (NL), Pontypridd College (UK), the OAED (GR), UGT-Metal (E) as well as vocational training centres in Austria, repair shops and field experts all over Europe, Association of Motor Vehicle Importers (GR), Vocational Training Board of the Motor Industry in Sweden (S), KWK-Kraftfahrzeug-Werkstatt-Konzept GmbH & Co. KG (D) and two colleagues, Institut Technik und Bildung –ITB (D), Berufsbildungsinstitut Arbeit und Technik – biat (D).). The concept is an answer to the structural changes and the transition from traditional garages to modern service centers featuring customer oriented quality work on high-tech cars.

The vision of the Car Mechatronic profile is the creation of a broadly trained customer oriented technician for future work in a service oriented sector. The Car Mechatronic is able to deal with all aspects of modern high-tech cars and with modern micro-processor based diagnostic tools as well as with the service demands of the customers. Highly qualified technicians should also actively participate in the shaping of work, technology and work organization. Therefore abilities and competences have to be developed.

The target is to overcome specialized occupational profiles in supporting a comprehensive and holistic work process by avoiding specialization during the initial training. This should help to create a flexible technician for the future service sector featuring a reduced repair orientation in favor of a concentration on service, diagnostics and customer orientation and high quality work. A flexibility to adapt to new and promising business fields is also important (SPÖTTL 1997a).

In many European countries occupational profiles based on a Tayloristic division of work in car workshops are still dominating. The meanwhile integrated technology and the average size of a workshop of approximately seven employees blocks such a division of work The reason for this are tasks which have to be tackled within short time units. If a workshop wants to work effectively each and every employee must be able to take over various tasks. With regard to the networking of cars the entire vehicle must be mastered in order to safeguard the accomplishment of a complete service task (The reason for this are tasks which have to be tackled within short time units. If a workshop wants to work effectively each and every employee must be able to take over various tasks. With regard to the networking of cars the entire vehicle must be mastered in order to safeguard the accomplishment of a complete service task.). It is therefore necessary that a technician is able to take over as many tasks as possible in order to work efficiently.

Specialists are only called in for very complicated cases which are, however, quite rare (The all-round technician with a high grade of responsibility has already been dominating the US American sector since a decade. This results in the fact that a technician is taking care of the greatest number of cars (around 140 vehicles; highest value encountered in Europe: appr. 120 vehicles). However, the qualification concepts cannot be compared with those of the European sector. So far it is not likely that they will gain importance in Europe.).

This comprehensive range of tasks requires qualification systems which are not oriented towards a vertical or horizontal division of work but which concentrate on holistic processes from the practice.

The curriculum is designed around the “car as an entity” and is focusing on the work and business processes in service stations. It is structured into fields of work process related core vocational work tasks. The core work tasks represent the core work process. The training starts with the servicing of a vehicle in good working order. It then deepens into overhaul and repair of assembly groups and vehicle components. Finally it opens up to provide a deeper insight into the interconnections and functional principles. This will facilitate the transition to continuing vocational training.

Aspects such as “exemplary learning” and “understanding of the system”, the idea of quality, the service aspect and an orientation towards work process knowledge play a major role in the curriculum structure as well as in the training process.

The recommended entry level for Car Mechatronic is post-compulsory graduation. In order to attain European qualification level V, the qualification level of skilled workers should be reached after 3 years’ training course which should also offer a link to later CVT leading up to the “Master Technician” level (SPÖTTL 1995).

With respect to the European dimension, core work tasks of skilled work have to be defined as a common European basis. The special interests and tasks of the different countries – the European regions – will then be integrated by optional/compulsory objects of skilled work. This could be done with the aid of a concept of open, dynamic occupational profiles with a European wide core of approximately 2/3 of the profile and an open area for the other 1/3 of the whole profile.

The concept of the European occupational profile of a Car Mechatronic can be summarized in seven statements (SPÖTTL 1997b):

(1) The Car Mechatronic as a European occupational profile is the answer of vocational education and labor market politics to the challenges of the increasing globalization of the European car industry.

(2) The broadly designed occupational profile of the Car Mechatronic supports the current structural changes within the European automotive sector which is transforming from traditional repair workshops towards modern automo-

tive service centers entailing the emergence of customer-oriented quality work.

- o The occupational profile of a Car Mechatronic accomplishes a reduction of vertical and horizontal division of work (Taylorism) in a way that
- o the car as an entity is the focus of all service and repair tasks,
- o each service and repair task is regarded and performed as a customer oriented service task (orientation towards company related processes),
- o responsibility and quality consciousness for the execution of service and repair tasks is enhanced.

(3) The training concept of the Car Mechatronic during initial training is especially oriented towards work process knowledge and will only deepen this knowledge in a specialized systematical way during specialized training. Thus the traditional – above all school oriented – curricula for automotive professions will be moved "from the head to the feet".

(4) With the aid of new contents structures the car as an entity shall be the center of occupational training.

(5) The concept shall promote innovations in work organization of the workshops: Introduction of the team concept in larger enterprises; company process oriented work organization; increase of in-firm flexibility of the employees; improvement of the cooperation with car manufacturers as well as of different learning environments.

4.2 Curriculum Macrostructure

The curriculum of a Car Mechatronic is based on an holistic structuring of the content and takes account of work tasks in quality-oriented service stations. The object, traditionally oriented towards technical aspects, is not only enriched by other dimensions. There is a change of perspectives of workshops which are about to develop from repair centers to service stations. Above all account is to be taken of the increasingly important service perspective, of tools, methods and organization of skilled work and of the social and subjective challenges (SPÖTTL & GERDS 2002).

Traditional occupational profiles for the automotive trades are structured in a way that they include basic scientific and technological knowledge and basic work-related skills at the beginning of the training (e.g. in metalwork) and then step by step deal with the important assembly groups and components of a car (There are good examples for the mentioned approaches in all European countries. Documents underlining this statement are the occupational profiles and curricula for the automotive sector as well as for most of the other sectors of industry and trade.).

The car as an entity is hardly ever the subject of vocational training. This is not only due to the fact that the skilled trades are specialized either on the mechanic or the electronic systems of a car or even on other components such as the engine, brakes, or bodywork. This subject systematic, technology-centered curriculum design presents the following disadvantages:

- The content deviates largely from the work process.
- As soon as the basic training is separated from the work process it leads to motivation problems among the trainees.
- The curricula are overloaded with topics and subjects which have no practice orientation.
- The acquisition of inter-connected areas of knowledge is not promoted.

As an alternative, a work-process-related curriculum is proposed here, with the intention to abolish the horizontal and vertical division of work: Vocational training for the car as an entity as well as for a modern automotive service business is the focus with the aim to qualify all-round technicians.

The subjects at all levels of differentiation are designed in a work-process-oriented way. In order to attain this objective, work processes in car service stations had to be carefully analyzed (A research method was developed for this endeavour. With the aid of case studies work processes were identified and structurized in expert interviews. In workshops carried through with "expert technicians" we compiled a sample of 70 tasks crucial for the car service. These tasks were structured according to a concept which enables a beginner to develop into an expert. In cooperation with shop floor experts, 15 work process related core tasks were selected from the 70 work tasks. Based on the actual requirements for work, technology, and society and the "re-structured" situations and problems the competence development model described here aims at a qualitative re-organization of a philosophy of "regulation-guided know-that" towards "experience-based know-how" (DREYFUS & DREYFUS, 1987)).

With regard to dealing with work oriented issues, this will be successful if there is a differentiation between three dimensions (From here on called "dimensions of work and learning".)

- the *objects* of skilled work (issues based on their relevance for the work process and the functioning of technology),
- the *methods*, *tools* and *organization* of skilled work,
- *the company-related, social and subjective demands on skilled work* and technology (demands resulting from standards, legal issues and the wishes of employees, company and customers).

It is therefore no longer sufficient to include more or less detailed catalogues of scientific or technical facts in a commercial or technical vocational curriculum. When a customer wants exhaust emissions minimized (demands aspect) in order to be able to use the vehicle in compliance with legal regulations (object aspect), it is necessary to exploit the potential of possible reductions of exhaust emission figures (object aspect). This is only possible if – by means of test and measurement procedures and with the help of the manufacturer's support documents (tools and methods aspect) –

a) the ACTUAL figures are accurately determined – i.e. measured – and

b) there is a reflection on how these figures can actually be reduced.

The fundamental objects of and demands for (skilled) work and related vocational training in this example are

- to assess the composition of the exhaust emissions and to carry out the comparison between the ACTUAL figures and the DESIRED figures,
- to connect and to use the measurement instruments and to read the measurement values,
- to draw conclusions about the “condition” of the motor management system in accordance with the composition of exhaust emission and the absolute exhaust emission figures,
- to carry out adjustments of the motor management system in accordance with the deviations of the exhaust emission figures from the (manufacturer’s) standards and the legal regulations.

The aspect of methods, tools and organization of the skilled work concerns the choice and use of the correct test and measurement instruments for a specific application, the information value and comparison of data, by taking into account the manufacturer’s documents or rather the target data given in them, and conclusions about the motor management system or adjustments of the system itself and the respective effects of these adjustments. Guidelines, instructions and documents for the correct use of tools and test instruments are necessary as well as familiarity with the regulations in the area of desired values and tolerance limits for exhaust emissions.

The contents of instruction with regard to the demands for skilled work and technology includes all aspects and requirements from the point of view of the user/customer, the company, the legislator, standards and norms, and finally the skilled worker/trainee himself, who ensures the correct execution of exhaust emission testing measures and at the same time adheres to legal regulations. In addition there is the customer who demands highly competent advice and wishes to make his or her decisions based on economically advantageous solutions which at the same time promise to be successful.

Each of the three skilled work-related dimensions of work and learning correlate with one another. In this way the demands for skilled work and for technology are reflected in the object of the skilled work and also in the methods, tools and organization of the skilled work.

The consequence for the shaping of a curriculum is that the three dimensions of work and learning of an instruction area will indeed be formally divided but at the same time the content will be interdependent. In each instruction area broken down in this way, the training and/or educational objectives are formulated to more closely characterize the curricula of the learning process and the required results (SPÖTTL 1995, RAUNER & SPÖTTL 1995).

The content of the curricula is structured in a way that it is linked with the overall contexts fundamental for the occupation or group of occupations and related to work processes with the aim to develop expertise in work processes.

For the skilled car technician the fundamental object of skilled work is

- the automotive as an entity with its relevant use- and user-related properties as a traffic/transport system,
- the documents, tools and methods necessary for satisfying the quality demands and characteristics of a motor vehicle as well as
- demands influencing the motor vehicle and its use and determining purchase and after-sales service (e.g. firm, customer, legislator, standards etc.).

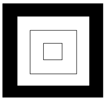
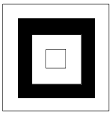
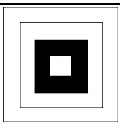
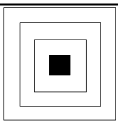
Here the three above-mentioned interconnected dimensions of work and learning will be broken down into learning areas. The car as an entity will be further broken down in accordance with the three subject dimensions. This is shown in Table 6.1.

The fields of tasks for skilled work are work process oriented and have to be identified via a research process. The instruments to be applied are case studies as well as expert interviews adhering to a method especially developed to identify and open up work processes. As research work is quite detailed it is shaped in a way to point out the fields of tasks for skilled work. It is, however, a kind of "iterative" process to identify the most important work processes within a branch or a sector and to combine them as the "core tasks" for an occupational profile (Studies carried through in other sectors confirmed that about 15–20 so-called "occupational tasks" are sufficient for the design of an occupational profile.)

The vertical structure of the profile adheres to the work process. Four learning areas are created for fields with different competence levels:

- Orientation and overview knowledge,
- Coherent/comprehensive knowledge (system knowledge),
- Detailed and functional knowledge (function of systems) (This area plays the most important role in traditionally oriented curricula. It is, however, just one aspect of all requirements for car technicians.),
- Specialized systematic and advanced knowledge.

Table 6.1: Work process oriented working tasks as structuring instruments

Learning areas	Fields of tasks for skilled work
 **Orientation and overview knowledge**	**Learning area 1:** **The car: the basic service** 1. Standard service 2. Repair of basic wear and tear 3. Vehicle care 4. Administrative services
 **Comprehensive system knowledge**	**Learning area 2:** **The car and its architecture: services and supplementary installations** 1. Standard default extension and supplementary installations 2. Main inspection including summer, winter and holiday check-ups 3. Service tasks (emission control, periodical inspection)
 **Detailed and functional knowledge**	**Learning area 3:** **The car and its components: fault diagnosis and repair** 1. Repair of faults (chassis, body, steering ...) 2. Trouble shooting and repair 3. Special extensions and supplementary installations 4. Repair of aggregates and components
 **Specialized advanced knowledge**	**Learning area 4:** **The car and its construction: expert diagnosis and repair** 1. Special diagnosis and repair 2. Repair of collision damages 3. Claims 4. Checking measures in systems – alternatives

These four vertical learning areas are filled with fields of tasks for skilled work, the key work tasks. The 15 key work tasks become objects of the competence development process (details cf. below). They may be understood as the "content dimensions" of a work process oriented curriculum.

They help to access

- the entire car,
- the service dimension,
- the work and business process.

The comprehensive structure of the profile integrates both dimensions, the vertical as well as the horizontal one.

The three dimensions of work and learning are widened up by objectives for practical and theoretical training as well as by the already mentioned occupational tasks. The work tasks are the core content of the work process-oriented curriculum. Therefore it was necessary to point out the nature of skilled occupational work as well as the knowledge of the competences necessary for skilled work in the car service sector.

The applied structuring scheme corresponds to the categories of "knowledge" – categories which progress from orientation knowledge and an overall view, system knowledge, to detailed knowledge of functions and further – as a fourth step – to specialized technical systematic knowledge. Thus four important structuring characteristics are given and, on the other hand, the relation to the work process is established.

The structuring process of the curriculum will consider the trainee's previous knowledge, which he or she normally acquired as a car purchaser, as a user, or as an interested person only. The perspective of the user is therefore decisive for the choice, scheduling and structuring of the subjects in basic vocational education. This also concerns the three dimensions of work and learning. In this way skilled work and technology in the concrete form of their practical value becomes a starting point for vocational education.

The curriculum structure proposed here represents skilled work and technology not only in their abstract function but also by continually considering demands for technology and work as an expression of business, social and subjective practice. This is the only way to experience work and technology as something shapable (SPÖTTL & GERDS 2002, BLINGS & SPÖTTL 2003).

From the point of view of effective training for work in a company, this approach promises a closer bond between vocational training and the company's organizational development, as from the very beginning the trainees learn to experience "their work" in the context of the overall processes within a company. In the course of his or her training the trainee always comes to grips with this increasingly detailed knowledge in the context of the comprehensive business procedures within a company. This is a precondition of considerable importance for quality awareness, quality work and the development of a participative organization within the company.

A curriculum structure like the proposed one facilitates the organization of a cooperative form of vocational education because both school and company can refer to a common work-process-related contents structure. The division of responsibility between cooperating learning environments (association of learning environments) arises naturally out of the complementarity of the training/educational aims.

The choice of the “instruction contents” is carried out in a way that results in content “correspondence” within the horizontal dimensions of learning; training objectives will be related accordingly. The angle of vision on aspects of the motor vehicle is progressively widened. Thus it is ensured that from the beginning of the training the trainee can fit all detailed knowledge into the overall structure of his or her occupation in a systematic and work-process-related way. What remains in each learning area is both the closely knit content correspondence and the comprehensive relationship.

It has to be stressed that the vertical axis of the curricular structure represents a link between the learning areas. At the beginning the contents of learning area 1 is dominating and gives an overview on the occupational area and the knowledge. Later emphasis is laid on learning areas 2 and 3 for more detailed and deeper studies – first into systems, second into components – without loosing contact with the learning areas worked on beforehand. At the end of the competence development process, learning area 4 provides a deeper insight into the principles of function and interrelations, physical and chemical details and offers a link to further vocational training. All previous learning areas are taken into considera-tion. The curricular structure supports the concept of the Car Mechatronic by dealing with occupational challenges from the start. The column “demands” adds the element of reflection on technology and work as a prerequisite and basis for shaping competences. Shaping competences (“Shaping competence” in this context means that students develop the capability to shape their work and learning environment as well as technology.) will be developed during profound reflection processes.

The requirements may vary in each country and each region of Europe. Customer expectations, legal stipulations and the individual’s demands regarding work are influenced by certain traditions and perspectives. Even technological requirements such as roughness or comfort, load capacity or maneuverability vary between big cities and rural areas.

The objectives are influenced by pedagogical or educational processes, by economic or political interests. They are obtained by a reflection on objects, tools, methods and organization of skilled work in the light of the requirements of work and technology. The objectives should, however, always be committed to the shaping principle.

5 Design and Accreditation Process

During the last decade various studies about European technical education and training systems – mostly based on comparative research approaches – have been undertaken. The respective results of this research provide a sound knowledge on the institutional structure of European TEVT-systems. Nevertheless there is a lack of systematic reflection on the differing cultural, historical, political, and social background of TEVT-systems. Particularly this knowledge is important to improve cooperation between actors of different systems. The same is true for the development of an appropriate research concept.

Within this framework an important role was assigned to a national and European oriented Social Dialogue within the selected sector. This dialogue not only concentrated on the design but also on implementation issues of the occupational profile. The design issues were taken into consideration on the basis of previous research results. Changes were made where the suggestions of the Social Partners (with their experts) promised to intensify the work process orientation. This process was carried through at a national level, driven by the partner countries, as well as on a European level, driven by the Central Team. It was an important task for all partners to point out the most influential Social Partners at both national and European level. Based on this discussion, the corner points of a European Occupational Profile were accepted by the Social Partners.

Figure 6.1 shows the communication structure within the project up to the Social Partners. The Central Team was composed from project partners and had to

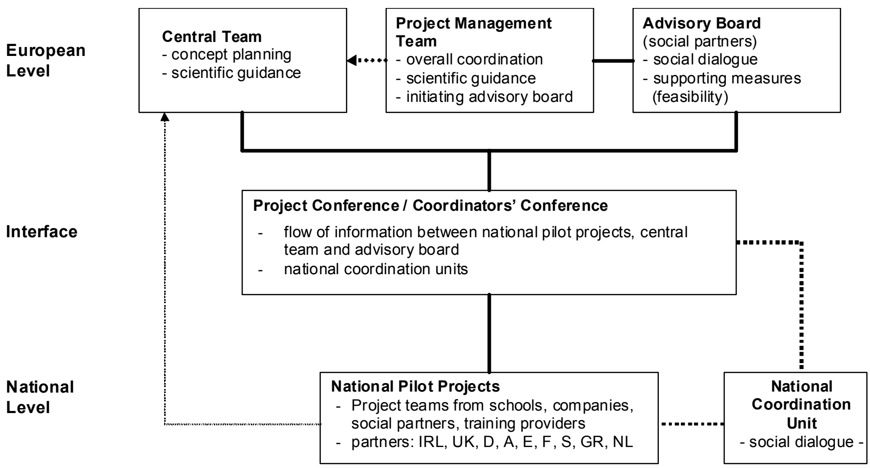


Fig. 6.1: Dialogue and cooperation structure of the Car Mechatronic accreditation project

ensure the progress of the project with the support of the project management. A key role was assigned to the Advisory Board which also encompassed selected Social Partners. This procedure safeguarded the discussion on the development of occupational profiles in national bodies and on the political level of vocational education. The members of the Advisory Board gave valuable support during the introduction of the occupational profile in some countries.

The national Social Dialogue should reach the following three goals:

a) Acceptance of a European Occupational Profile by the social partners on national level and initiatives for its success.
b) Support of the implementation process within the national cultures and the legal accreditation processes.
c) Initiatives of the Social Partners on European level with the aim to reach European acceptance.

In cooperation with the Social Partners the project partners from nine countries developed an Occupational Profile which was widely accepted by the automotive service sector. After finalization of this work the implementation concept was designed and the national Social Dialogues were initiated. The social partners from the six countries of Ireland, the United Kingdom (Wales), Germany, Austria, Sweden and Greece intensively participated in the Social Dialogue and gave a lot of support to the preparatory work for the implementation of the Occupational Profiles. However, the national dialogue processes already lead to different results. The specific cultural context and the national interests were manifested by various modifications of the profile (Based on the Occupational Profile 6 versions were developed in order to take into consideration the specific country interests. Further adaptations were carried through in the respective countries.).

The Social Dialogue initiated on the national level had many faces both in national and transnational terms. Austria reports a success story. The social partners (employers associations, employees association Vienna, trade unions, representatives of teachers and schools, school supervisors) very quickly agreed upon the introduction of the concept as a pilot project for the Vienna region. After three years the project has consolidated itself. Due to the scientific guidance during the implementation phase it was possible to state that the required respect of national institutional framework conditions required by the Maastricht Treaties had not remained without consequences during the implementation of the curriculum concept. Some reorganization was necessary to implement the occupational profile.

Greece made use of the Car Mechatronic profile within the framework of a reform of vocational education and introduced the occupational profile as a crystallization core of a reduced number of – 4 remaining out of 14 – automotive occupations. The concept structure remained unchanged. After some trial years new findings on the sustainability of the concept are now being presented (OEED is the decisive institutions in Greece for the introduction of new occupational profiles.).

In Sweden the occupational profile was implemented nearly unchanged within a pilot phase at two colleges and is in its preparatory phase today. Wales carried through an adaptation to national structures. In Wales, the concept was entirely integrated into the module system. Predominant concept features, such as the “car as an entity” and others were thus abandoned.

In Austria, however, the core curriculum remained unchanged. The remaining traditional “objects” were arranged around the core curriculum. At the moment the occupational profile is extended to further school districts.

Similar to Germany, Ireland is in the midst of a Social Dialogue with regard to a modification and introduction of the concept. In Germany, a mixed form is emerging which means that the concept philosophy will basically remain unchanged – as already realized in the Master’s training. Concrete modifications must, however, be envisaged in order to fit the profile into the existing traditional framework regulations (educational regulations, framework curricula). More details are given in RAUNER and SPÖTTL (2002).

Based on experiences made so far with the Car Mechatronic concept the conclusion may be drawn that in spite of the well-known and accepted cultural differences (NICOLINI 1996) there are no major barriers for the introduction of a transnational concept from the users’ point of view. Nevertheless it cannot yet be predicted how the national transformation process will develop and whether there will be a considerable leveling after all. An important role is played by the Social Partners. They may motivate or stop the process of the implementation of new occupational profiles.

The experiences made on European level may rather be seen as an indicator that differences in the TEVT-cultures are considered so important that the establishment of European occupational profiles seems to have be only successful if both social players as well as a highly qualified workforce are available for initiating the implementation processes.

The discussion with the social partners revealed a considerable discrepancy in the objective estimation to make the European service sector competitive and at the same time to overcome national qualification traditions. The discussion will still go on for a long time. It has just begun. Whether the automotive industry will enter and finally control the discussion or whether the industry will continue to enforce their own qualificational concepts is another question to clarify. It cannot be excluded that global industry specific qualificational profiles will be established quicker and more successful than European occupational profiles. This would eventually mean a great defeat for the development of a European occupational educational tradition. What is to be feared is a step back towards “remaining tasks” not covered by the industry. Social Partners are in a position to establish European occupational profiles. They should use this opportunity for ensuring more competence for the European Union.

With a view to the European occupational profile of a “Car Mechatronic” the European social partners were recommended to accept the proposal submitted by the project group and the European industrial trade union on the occasion of the spring meeting 2000 in Bonn (Germany): to open a sector oriented European dialogue of vocational education and to work on the objective to establish a European vocational education policy. This would represent a major step towards the abolishment of particularism and to tackle great challenges. Only then the concept of the Car Mechatronic will be discussed in the European Commission and will lead to entirely new forms of organization in schools.

6 Conclusion

With the above mentioned procedure the project group developed a European profile and curriculum of the Car Mechatronic following the changes of paradigms in the car service sector. In the light of the concept of an open dynamic Occupational Profile research on core, compulsory and integrative fields in the European context and their integration into the curriculum are still worked on.

The research and development work on the European automobile sector proves that it is basically possible

- to carry through research on qualification in Europe,
- to access very complex sector structures with regard to the need for qualification,
- to carry through a Europe oriented development of occupational profiles beyond cultural differences.

The developed occupational profile of a Car Mechatronic excels by a work process oriented structure. It therefore differs considerably from the traditional specialized systematical orientation of occupational profiles.

The work process orientation can also be seen as an response to the fact that car workshops need above all the all-round automotive experts who master vehicle systems and diagnosis techniques und who underpin business processes. The specialized repair expert is no longer in demand.

The used structurization concept offers decisive prerequisites for the development of competence because the structure adheres to the development logic from "beginner to expert" discussed by Dreyfus/Dreyfus. Although this approach is not yet fully developed it nevertheless reveals clear points of contact for competence development.

The concentration on work processes seems to be also adequate to pursue an inter-country development of an occupational profile. One of the reasons seems to be that contents issues have to be clarified first. The country specific questions and issues linked to the educational systems also have high relevance. A broad Social Dialogue offers considerable opportunities to develop inter-country perspectives. However, it must not be underestimated that the European vocational education systems differ considerably and that no uniform concepts can be reflected there. Therefore the transfer of convincing philosophies to the national level is crucial. This can only be successful if the Social Partners and the vocational education actors of individual countries support this process.

With regard to the vocational education research it may be stated that the development and evaluation procedures with regard to initial training and CVT and above all research on qualifications are yet to be established and scientifically backed up in European research approaches and discussions. So far research on qualifications is dominated by industrial sociology and work-psychology/work sciences. While the first concentrates on company based social systems, the latter is focused on narrow "sub-vocational" skill performance. Neither of them support an educational approach towards comprehensive Occupational Profiles based upon work process knowledge and the shaping principle. With regard to vocational education the European researcher community is still at its very beginning. If ever, only randomly selected research problems with a connotation of TEVT are being worked at.

Other issues of concern such as entry and recruitment levels or the duration of a training course are subject to verification in discussion processes going on in the field of education and training, with the social partners and policymakers of the EU and the different European countries. All of these players have a certain interest in shaping education and training. It is to be hoped that as a result of this process the Car Mechatronic will emerge as a prototype of a European occupational profile and that the concept will not just be reduced to the smallest common denominator (BROWN & MANNING 1998). In general it would be a great advantage to establish a social vocational educational catalogue for the development of a European approach of vocational education. This would exert a considerable influence on the further development of European vocational educational issues.

The example proves, however, that a lot of clarifying questions have still to be answered. A Europe oriented research approach for vocational education research is still to be established. Moreover the role of the Social Dialogue for the support of such approaches should be clarified.

Further very basic questions are how research institutions and Social Partners should cooperate for the identification and development of necessary occupational profiles, which organizational framework should be created and how a transfer of findings to the national framework to be respected might be managed in order to safeguard sustainability. Considerable steps must therefore be undertaken in the years to come in order to ensure the success of the discussed approaches.

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Part 2
Enterprises and Companies

7 Performance Measurement from a Macroergonomics Perspective

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For industrial organizations, as well as others, the general pursuit of optimized performance is nothing new. Changed frame conditions, for example globalization, increased transparency caused by information technology and the world wide web as well as increasing customer demands result in a performance pressure – not only for companies but also for the shop floor level. But other developments like the discussion about corporate social responsibility (ZINK 2003) – or more generally about sustainability in its triple bottom line understanding e.g. in the context of global supply chains – are new demands for companies as well.

Besides companies and their people, society in general is challenged by a globalized economy, but also by companies being unaware of their societal responsibility. In particular, unemployment as well as the increasing healthcare costs of a growing part of older citizens are a huge financial burden.

When considering these changes and challenges, one has to ask whether ergonomics or human factors can contribute to solving these problems. Therefore, the understanding of ergonomics or human factors has to initially be clarified – especially through a historical perspective and by looking at its "performance dimensions".

1 Focus and Target Groups of Ergonomics and Human Factors in a Historical Perspective

Jastrzebowski's outline of ergonomics in 1857 described the science of work as follows: "The Science of Work, understood in the widest possible sense of the term "work", may be divided into two main disciplines, the science of useful work, which brings improvements or is commendable, by which we mean the good use of Man's forces and faculties with which he has been endowed by his Maker, or the use for the common good; and the science of harmful work, work

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that brings deterioration, and discreditable work, by which is meant the contrary use and intention to use the said forces and faculties." (JASTRZEBOWSKI 1857, p. 15) Without focusing too much on his interpretation of work, there is a distinction between "useful" and "harmful" work and there is a very broad understanding of what "work" means.

Looking more than a century later (1973) at a mission statement of the German Human Factors and Ergonomics Society (Gesellschaft für Arbeitswissenschaft) one can find the following definition: "The content of Ergonomics is the analysis and design of work systems and equipment, whereas the working man in his individual and social relations to the other elements of the working system is the starting point and objective of consideration." (GESELLSCHAFT FÜR ARBEITSWISSENSCHAFT 1973, p. 3) "The measures of work design focus on occupational health and safety, social suitability and technical and economical rationality." (GESELLSCHAFT FÜR ARBEITSWISSENSCHAFT 1973, p. 4)

In 1987 Luczak et al. tried to get a consensus between most of the active scientists in this field and as a result published a "core definition" of work science (LUCZAK et al. 1987, p. 59): Ergonomics or human factors is the system of analysis, organization and design of technical, organizational and social conditions of work processes. The objective is that working people in productive and efficient working processes

- have working conditions that are harmless, accomplishable, endurable and without impairment,
- see standards of social adequacy fulfilled according to work content, task, work environment as well as remuneration and cooperation,
- are able to develop freedom of action, gain the abilities, preserve and develop their personality in cooperation with others.

Luczak summarized this definition in two main objectives: "to design work humane and effective" – including also efficiency (LUCZAK 1998, p. 6). Therefore, it has always been an objective of ergonomics to support economic- as well as people-oriented improvements within organizations. This duality of productivity (efficiency) and people orientation might no longer be enough, when considering the challenges for companies roughly described above.

Therefore, from an ergonomics point of view, this duality has to be given up or enlarged in introducing a stakeholder perspective with at least integrating the customers and society as additional stakeholders more explicitly. This has been done within GfA in 1999, when during 1997 and 1998 a new mission statement was developed, reacting to the above described changed basic conditions. Among others "work" was no longer "only" related to work systems (e.g. within a company), but included also to unpaid work (like voluntary work, housework, community work etc.). Regarding the target groups, a stakeholder approach has been realized and the societal responsibility (e.g. to maintain, create and (appropriately) distribute humane, economically and environmentally compatible work) became more important (GESELLSCHAFT FÜR ARBEITSWISSENSCHAFT 1999). In this sense, the very broad understanding of work (e.g. including entertainment) of Jastrzebowski came up again. This has also been shown in a memorandum concerning the structural change of work and the thereby resulting research questions. (see GESELLSCHAFT FÜR ARBEITSWISSENSCHAFT 2000)

Though this is not totally new (there has been a customer focus in discussing usability aspects of products and the contribution of OHS to society), it might be a new perspective in re-defining performance from a macroergonomic perspective.

To broader the discussion with an international perspective it is useful to refer to the definition of ergonomics/human factors of the International Ergonomics Association (IEA): “Ergonomics (or human factors) is the discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that uses theory, principles, data and methods to design in order to optimize human well-being and overall system performance. Ergonomists contribute to the design and evaluation of tasks, jobs, products, environments and systems in order to make them compatible with the needs, abilities and limitations of people.” (IEA 2000) This definition is a very broad one including stakeholder aspects – at least implicitly.

Taking a macroergonomic perspective, two further definitions might be helpful:

- The definition of macroergonomics by Hal Hendrick: “Macroergonomics is concerned with human-organization interface (HOI) technology (based on a top-down socio-technical approach)” (HENDRICK 2002, p. 3) and
- The IEA’s definition of organizational ergonomics: “Organizational ergonomics is concerned with the optimizing of socio-technical systems, including their organizational structure, policies and processes. Relevant topics include communication, crew resource management, work design, design of working times, teamwork, participatory design, community ergonomics, cooperative work, new work paradigms, virtual organizations, telework, and quality management” (IEA 2000).

Comparing both definitions, again there is a very broad approach with a lot of similarities between “organizational ergonomics” and “macroergonomics”. But there is also the question of the understanding of two key definition elements: the understanding of “systems” in general and the understanding of “socio-technical systems” in particular.

First of all one can state that “organizational ergonomics” includes “community ergonomics”. This corresponds with other definitions of ergonomics, where the relationship between macroergonomics and industrial policy or society as a whole is obvious. (see LUCZAK et al. 1987, p. 63) When analyzing the definition of “community ergonomics” one can find: “community ergonomics can be defined as a design approach to the interface between people and system design in a societal context. CE theory is built on the foundations of human factors and ergonomics, socio-technical systems theory, quality improvement, behavioral cybernetics, and the problem-solving technique of Breakthrough Thinking™.” (SMITH et al. 1994) This definition shows, that the idea of a socio-technical system has been transferred to a community. The more advanced development overcomes the critical remarks about this approach in (e.g. German) literature (see e.g. SYDOW 1985). These remarks refer to the fact that although they define socio-technical systems as open systems, their main focus lays within the organization and its social and technical subsystems. Accepting the broader approach of socio-technical systems theory and design (e.g. within community ergonomics) two dimensions are not explicitly included: economy and ecology. Therefore, in the 1970s, Rühl (see RÜHL 1974) and the 1980s Zink (see ZINK 1984) started to re-define socio-technical systems as socio-technological systems and comprehending the meaning of "technology" as the way to realize a technique, including organizational, economical and later also ecological aspects (ZINK 2000, p. 924). Nevertheless, this definition also focuses more on the subsystems within an organization and has the environment of the organization as an impact factor for the organization instead of discussing the impact of the organization e.g. on customers or society as a whole – which leads again to a stakeholder-oriented approach.

Looking at other fields – partly also related to macroergonomics – like quality management or general management one can also see broader and more holistic approaches in the last years.

The emergence of concepts like Total Quality Management, Excellence Models or Performance Management results from this need for broader, more holistic approaches. Most of these concepts, at least partly, contain some kind of stakeholder orientation. (see ZINK 1999a)

The consideration of stakeholders – and therefore the concept of effectiveness is gaining much more importance in satisfying the relevant stakeholders of an organization. This approach also has an emphatic impact on the general comprehension of performance and the formulation of requirements as well as performance standards. This will be shown in the following chapter before clarifying whether the understanding of performance under a macroergonomic perspective has to be re-defined.

2 Redefinition of Corporate Performance Measurement

During the last decades it has become more and more obvious that managing a company mostly based on financial data may not be adequate in a global and more dynamic economy. As a consequence several disciplines, like accounting or quality management, tried to develop more holistic concepts to improve managerial instruments to react on changed basic conditions. All of these instruments included a stronger stakeholder orientation and a re-definition of performance.

Accepting this need for a stakeholder orientation leads to an increased importance of effectiveness, and the question of how to measure effectiveness with regard to the relevant stakeholders. But one also has to consider that stakeholders are demanding efficiency: Investors want the budget be to handled economically with performance and support processes to be designed to reach the profit with expenses that are as low as possible. Customers expect products and services for low prices as well. The fulfillment of the efficiency target is therefore part of the entrepreneurial effectiveness, measured and based on the demands of important stakeholders. To neglect these efficiency requests would result in a removal of capital or a loss of customers and could finally lead to the economic breakdown of an enterprise. (STEIMLE 2008, pp. 198–199)

Regarding efficiency there is always the task to optimize the input-/output relationship. In this sense, the productivity of processes is at first an appropriate measure of efficiency in an organization. Because there is not only one production factor, different partial productivities have to be taken into account – without the possibility to summarize this partial productivities to only one indicator.

In opposite to the "traditional" management theory previously described, Pfeffer and Salancik regard efficiency as inappropriate to estimate organizational performance: "Efficiency is relatively value free. It asks how much is produced at what cost. What is produced is not considered." (PFEFFER & SALANCIK 1978, p. 34)

Indeed an exclusive consideration of efficiency targets is neither an adequate explanation nor sufficient for decisions to be made by the management. To consider efficiency as the only relevant indicator of business could lead to wrong decisions: Producing highly efficiently does not help, if the products or services are not accepted by the market. This leads to the old saying, doing things right is not enough, you have also to do the right things! (see STEINMANN & HENNEMANN 1993, p. 58) These "right things" must be related to the relevant stakeholders. Using merely "traditional" economic indicators does not help in this situation.

The long-term survival of an organization depends – among other dependencies – on its resources. If the resource base is defined by the contributions of relevant stakeholders, their demands have to be taken into consideration. Accordingly, the objectives of an enterprise are the requirements of the stakeholders, whose contributions are essential for the survival of the organization. (NÄSI 1995, p. 100) The relevance of these objectives is given by the fact that the willingness of respective stakeholders to deliver important resources is connected to the pursuit and achievement of the objectives. The ability of an enterprise to fulfill the requirements and expectations of the relevant target groups is characterized as effectiveness by PFEFFER and SALANCIK (1978, pp. 32–32F).

The measurement of effectiveness as defined in the last paragraph is certainly not without problems. For the evaluation of effectiveness, there is a need for key criteria and indicators, whose degree of accomplishment can be determined. (BEA & GÖBEL 2006, p. 12) These key criteria represent the expectations and demands of different stakeholder groups. But there might be two problems: Within one stakeholder group there could be different demands, and different stakeholder groups might have competing expectations and demands. In other words, something that has been regarded from one stakeholder group as effective could be ineffectively based on the interests of others. (PFEFFER & SALANCIK 1978, p. 37)

Therefore, effectiveness is not based on an objective assessment of facts but it is an assessment on the basis of different interests, preferences and values of the stakeholders (WALTON & DAWSON 2001, p. 174). Because the preference-systems of the stakeholders may differ over time and the fact that many organizations act in different environments, the construction of universal criteria for entrepreneurial effectiveness is only possible on a very abstract level (VOSS 2002, p. 53). Accordingly, a company-specific evaluation of effectiveness has to consider the degree of satisfaction of the relevant stakeholder groups concerning their specific expectations.

However, as shown at the beginning of this chapter, even if effectiveness is seen as an important indicator, a consideration of efficiency is necessary. Pritchard underlines the central relevance of a combination of efficiency and effectiveness. He defines as a key indicator the quality in which a system uses its resources to achieve its objectives. (PRITCHARD 1992, HOLLING et al. 1999)

Taking this resource based view into account, performance measurement has to be redefined as a basis for a redefined performance management. During the last years there have been several publications dealing with this task. In combining effectiveness and efficiency measures new concepts have been outlined or existing concepts like international excellence models (see e.g. ZINK 2004) or the Balanced Scorecard (see KAPLAN & NORTON 1996) have been used. All of these concepts are based on a stakeholder orientation including efficiency indicators e.g. for measuring the "quality" of processes. There is a holistic and multidimensional approach in assessing the performance of an organization, understanding that results are normally based on several causes.

3 Performance Measurement and Human Factors: A Proposal for a Re-definition from a Macroergonomics Perspective[1]

So far it has been shown that the stakeholder orientation is a crucial element of a revised understanding of performance measurement or an adequate understanding of performance. Even if the stakeholder idea is not new (FREEMAN 1984) a discussion related to performance (measurement) from an ergonomics perspective has not taken place. As shown in the first chapter, for many years ergonomics has been concentrated on dealing with working conditions within a company (mostly within industry) – though Jastrzebowski included also "leisure" in his very first

[1] Some ideas of this chapter are taken from Zink K J (2002) A vision of the Future of Macroergonomics. In: Hendrick HH, Kleiner BM (Eds.) Macroergonomics: Theory, Methods, and Applications. Mahwah, N. J. and London: 347–358.

definition. The use of ergonomics in designing products or a broader systems approach as shown in community ergonomics appeared later. Taking these developments into account – as described in the mission statement of GfA or the definition of ergonomics by the IEA – one can discuss the question of performance measurement based on a stakeholder orientation (see e.g. ZINK 2002) from an macroergonomics point of view.

Accepting customers, employees, society and shareholders or owners as relevant stakeholders some examples of a re-defined understanding of performance measurement shall be described in the following:

3.1 Ergonomics Performance Indicators Regarding Customers

- **Number of products based on affective design**

Affective design tries to define the emotional relationship between people and products of any case. The term affective design received more attention in the field of Human-Computer Interaction. (see e.g. PICARD & KLEIN 2002) Affective design in ergonomics has been strongly influenced by Mitsuo Nagamachi. His customer-oriented product development process can be successfully used to meet customer demands. (see e.g. NAGAMACHI 2008) Additional aspects are concerned with the design of information (e.g. instructions for use) given with products or services. Additional performance indicators could be gained by asking the customers.

- **Number of products based on usability tests**

Instruments of affective design (like Kansei Engineering) are one approach to improve customer orientation (see NAGAMACHI 2008). They may, but do not necessarily need to, include usability aspects. Hence, usability is another ergonomic approach to improve customer orientation. Usability tests can be used to correct design faults before producing and delivering the product. Therefore, the interest in these tests by the industry is growing. The quality of these tests depends on the selection of "users" – whether they are representative concerning the target group, to which the product should be sold later – and the ergonomics knowledge of the people carrying out these tests. Additional performance indicators again are based on a respective questionnaire for customers.

- **Added value for the customer**

An added value can be created by designing products in a way that they can be maintained or repaired in an easy way, which is less cost intensive for the customer. This depends on the working conditions of the people doing these jobs. Therefore, product development processes should take care of these tasks as well. This means that the design of working conditions for repairing and maintaining the product has to be a part of the product design. (see e.g. ZINK & EBERHARD 2008) To make this added value visible for the customer a respective certification process could be introduced. This performance aspect would then be related to the number of certified processes a company can demonstrate.

3.2 Ergonomics Performance Indicators Regarding Employees

- **Work-Ability index**

One of the traditional goals of ergonomics is to design working conditions which are not harmful to any health aspects. The ability to work or to accomplish one's tasks, referring to physiological (and psychological) conditions, is of increasing importance for societies with a growing percentage of older people – and therefore companies with a growing percentage of older employees. The use of ergonomics knowledge, e.g. within Corporate Health Management Concepts is therefore gaining more and more importance. The measurement of the results of these activities can be done by key health indicators or more general in using the Work-Ability Index developed by Tuomi, Illmarinen and others. (TUOMI et al. 1998)

- **Employability index**

The ability to perform is not only based on psycho-physiological or health aspects but also on competencies. Again the demographic change in many Western countries leads to the challenge of keeping and improving competences within an older work force. Therefore, employability is another task to be accomplished in a new way. Taking an ergonomics approach the development of competences has to be embedded in the design of tasks. The work content has to deliver the possibility to learn – and therefore to keep or increase one's competencies. This should include a certain complexity and variability of tasks, combined with the need of cooperation and communication. Job rotation and the possibility to participate in continuous improvement projects can help to realize these objectives. To measure the employability of a work force specific questionnaires have been developed, e.g. by FRIELING et al. (2006).

- **Questionnaire results concerning satisfaction, motivation and personal growth**

Workability and employability are not the only aspects of an employment. Taking the objectives of ergonomics into consideration, satisfaction and personal growth are additional aspects of importance. Personal growth is again related to the competences one may acquire during work. If there is – besides professional competences – also the chance to improve one's social, methodological and personal competences, work is contributing to personal growth, which is connected with he motivational potential of a task. This can be measured by the Job Diagnostic Survey (HACKMAN & OLDHAM 1980). In addition, job satisfaction can be an indicator as well. There are different instruments that can be used in each country. In Germany Neuberger, among others, has developed such questionnaires (NEUBERGER & ALLERBECK 1978).

3.3 Ergonomics Performance Indicators Regarding Shareholders or Company Owners

- **Enlarged market shares**

The use of ergonomics principles like affective design or Kansei Engineering and the inclusion of usability tests as well as other design approaches to increase the added value for the customer lead to more customer-oriented products and, therefore, increased market shares. To enlarge this potential and to gain more acceptance for those approaches within companies, the ergonomics design principles should be applied within a holistic approach including technical, economical, as well as environmental aspects. As the understanding of ergonomic interventions is mostly only related to costs, a combination of different design targets and their interrelationships is better accepted. (see ZINK & EBERHARD 2008) The analysis of market research, including ergonomic aspects, could show the relevance of these product features.

- **Successful change management processes**

Many companies are unable to deal with change management concepts successfully, because they do not use a socio-technical or socio-technological approach. Restructuring organizations by changing only organizational structures, and not changing behavior as part of the organizational culture, will not lead to sustained success. To include people oriented aspects is the content of socio-technological approaches and a core definition element of macroergonomics (see IMADA 2008). In so far, macroergonomic concepts can even contribute to the survival of organizations. Therefore, the number of successful change processes could be a performance indicator.

- **Participation and continuous improvement indices**

Another core macroergonomics concept, which is also an essential part of a successful change management, is participation (see BROWN 2002). Besides participation in change processes the participation in continuous improvement processes, either in high involvement teams or in concepts like quality circles, are respective ways to involve people. This leads not only to cost reductions, but also contributes to the motivation and satisfaction of people. In this sense several measures for performance can be used: e.g. cost reductions and questionnaire results regarding motivation and satisfaction.

- **Better results for all stakeholders lead to better results for shareholders or company owners**

All above-mentioned methods like investing in customer-oriented products or services, taking adequate approaches for change, or involving people into the continuous improvement processes (and some others) – like process oriented work organization – contribute to better results for all stakeholders. The measurement of the (improved) performance can be done by adding the before mentioned single results, but also by an integrative approach in using assessments based on international excellence models like the European EFQM Excellence Model. (see EFQM 1999)

3.4 Ergonomics Performance Indicators Regarding Society

- Reduction of unemployment rates caused by companies

The contribution of macroergonomics to the success of a company by producing customer-oriented products, involving and motivating its employees, enlarging the competencies of its people or successfully managing change processes is also important for society, because these approaches are – among others – of high relevance for the survival of an enterprise. If the company does not survive because of economic failures, it results in unemployment. Insofar, the reduction of the unemployment rate caused by applying the above described instruments could be a performance indicator. (see e.g. GESELLSCHAFT FÜR ABEITSWISSENSCHAFT 2000, pp. 1–8)

- **Reduction of early retirements based on OHS problems**

The same is true for early retirements based on OHS problems as a consequence of problematic working conditions. Again society has to bear the burden. Newer approaches of health promotion based on management concepts that require a cooperation between enterprises, health insurance companies and governmental institutions can also contribute to a longer workability – as described above. (see ZINK 1999b) Other contributions can be received by using the concept of employability in addition. The performance measure is given by the reduction of early retirements based on using ergonomics concepts.

- **Accident rates within complex systems**

Ergonomics can contribute greatly to improving the safety in complex systems by respective design concepts. Such complex systems can be found e.g. within aero planes, power plants or even traffic. Another definition of “accident rates” can be seen in patient safety. In the context of technology implementation Carayon et al. have shown that a socio-technological change concept is able to reduce failures in using technologies and, therefore, can contribute to patient safety. (CARAYON et al. 2008) Besides the prevention of individual burden there is also a prevention of financial burden for society, which can be measured.

- **Problem solving rates in using the concept of community ergonomics**

Again macroergonomics can deliver “holistic” and “systematic” approaches that can help to contribute to the solution of complex problems that have taken decades to develop (SMITH et al. 1994). In the IEA understanding of ergonomics as human-systems-interface design, the community has to be designed to meet individual needs in the major functions provided by the community:

  - economic functions like possibilities to earn a living,
  - safety functions like a living environment free of danger,

- o housing functions like social gathering places or structures for commerce,
- o and social functions like opportunities to experience ethnic diversity to encourage acceptance and understanding. (SMITH et al. 1994)

Performance measures could be seen in positive results of such projects (see SMITH et al. 2002).

4 Conclusion

Changing frame conditions lead to a new and broader understanding of corporate performance. Performance has to include the views of different stakeholders as a basis for survival. These different demands have to be integrated in long-term organizational objectives to realize corporate effectiveness.

Stakeholder orientation, an integrative i.e. socio-technological systems approach, the balance of respective demands and a long-term orientation (including sustainability) are core-principles of ergonomics (ZINK 2002), that have to be taken into consideration in the context of performance measurement as well.

The few remarks and examples of a stakeholder-oriented approach of ergonomics (including a lot of macroergonomics aspects) show that considering ergonomics from this point of view can allow for a new understanding of measuring performance in this field. This has to lead to a new understanding of performance management based on a stakeholder concept as well.

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8 Technology Management

Dieter Spath, Karl-Christof Renz, Sven Seidenstricker

1 The Transition from Theory to Technique

The importance of technological innovations for maintaining and strengthening a company's competitiveness, especially in high-wage countries, has increased strongly. Market internationalisation, shorter product lifecycles and the soaring demand for resources are only a few of the possible explanations. In the global race for business deals, time is a crucial factor. Ideally, the period from the initial idea to the innovation should be restricted to an absolute minimum. The company's ability to manage complex systems is a further criterion that often tips the scales between success and failure. In other words, innovations alone are no guarantee of growth. Lasting success depends on the interaction between innovations and efficient complexity management (ARTHUR 2007). For this reason, in particular, technology development processes need to be reorganised, because in the turbulence of technological change the classic "technology push" and "market pull" models, as well as their combination, are no longer applicable.

The starting point for any innovation is knowledge. This encompasses both technological know-how, also referred to as technology, and knowledge of market requirements and trends. The synthesis of these two knowledge types paves the way for securing a "genuine" competitive edge. It is clear that, relatively speaking, the effort necessary to procure technological know-how is enormous (BROCKHOFF 2005). Technologies are generally based on theories. Most theories are universally valid findings of scientific research that help illustrate relationships by describing causes and their effects. Techniques, on the other hand, are the material result – in other words, the real-life application of a technology. Technologies build a bridge between universal discourse systems and techniques. They could be defined as knowledge about ways to solve technical problems linked to products and processes (SPECHT & MÖHRLE 2002, TSCHIRKY 1998, BULLINGER 1994).

For these reasons, the management and organisation of technologies for generating innovations should be embedded in every company as a central mission of

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corporate governance. Recent studies have shown an increased awareness in industrial companies when it comes to developing technologies, analysing and assessing their own technological performance, formulating technology based strategies and implementing measures. However, as far as the use of systematic technology management is concerned, there is still considerable leeway to make up (SPECHT & MIEKE 2006). A holistic concept that allows the company to identify and leverage technological potentials is therefore presented in the following. The first issue to consider is an explanation of the various dimensions of technology management before proceeding to a detailed discussion of strategic considerations.

2 Technology Management – A Multidimensional Approach

The definition of the terms theory, technology and technique yields to advances in understanding the concept of technology management. Management aspects make up the other side of the technology management coin.

Management today is often differentiated into two interpretative approaches (STAEHLE 1999, DRUCKER 1993):

- Management in the institutional sense refers to a group of persons and/or the individuals responsible for management tasks. They can be top management executives or members of the third or fourth management level such as foremen or team leaders.
- Management in the functional sense is based on a description of the processes and functions necessary to deliver services. These can be planning, organisational or controlling actions.

The term management thus subsumes all task- or people-oriented leadership and executive functions that can be accomplished through the situative application of management instruments.

By linking the terms technology and management, we arrive at the following definition: technology management comprises all executive tasks necessary to maintain and strengthen a company's technological competitiveness. These tasks include planning, organising and implementing as well as steering and controlling the technological know-how that is applied within the company to develop and draw up products and services.

The set of technology management tasks can be systematised by assigning them to levels with different functional and time dimensions (refer to Fig. 8.1).

The basic values and original corporate decisions on which technical actions are based are formulated in the framework of normative technology management. These basics should be reflected in the mission statement consistently with the corporate philosophy. It should be noted that "newer" values, such as the protection of resources, individual quality of life and social aspects, have significantly increased in importance (TSCHIRKY 1998).

In order to maintain or strengthen a company's ability to survive, the specific technology potentials relevant to its competitiveness need to be identified, developed, optimised and extended with the help of strategic technology management. This involves carrying out environment and business analyses, orienting research and development activities towards definite goals and optimally leveraging technological performance potentials. A good organisational grounding of strategic technology management and the use of suitable instruments are two essential prerequisites for developing success potentials.

The translation of strategic decisions into concrete projects and actions takes place in the framework of operative technology management. The proportion of operational tasks is much higher here than with strategic technology management. They tend to be more short-term in nature, and their accomplishment can usually be directly expressed and measured in figures. A whole series of indicators and calculation methods exist for this purpose in finance and accounting, such as project accounting, budgeting, cost and revenue accounting, financial planning and capital budgeting. However, it is not only monetary variables that are recorded and evaluated – quantitative variables relating to production or logistics as well as quality and time variables are also suitable as indicators.

Fig. 8.1: Technology management levels (BULLINGER 1994, based on BLEICHER 1992)

Strategic technology management plays a particularly important role in securing and developing success potentials owing to its future orientation. Decisions with a medium to long-term impact are also required in this context, frequently accompanied by large-scale investments. The strategic level of technology management is therefore considered in greater detail in the following.

3 Strategic Technology Management

3.1 Identification of the Technological Starting Point and Formulation of Technology Related Goals

The specification of the normative aspects of technology management results in simultaneously formulated guidelines for strategic technology management. The general conditions and constraints and the strategic starting point must be determined based on the parameters of the normative level. Account must be taken of the know-how and strategic considerations applicable to the company as a whole. Possible indifferences must be resolved.

The information about the technical starting point forms the basis for formulating technology management goals. The definition of goals is not an end in itself, however, but it must support efforts to develop technological innovations and help safeguard the success of technology management.

As mentioned earlier, the creation of success potentials and the ability to secure a competitive edge in the market are the most crucial aspects of technology management. Quantifying and presenting the outcomes of innovation and technology management activities is usually problematic, for one thing because the relations are not clear. With this in mind, VAHS and BURMESTER (2005) describe a "magic triangle" that shows the three goals cost, quality and time and the conjunction between them. In addition to cost, quality and time, factors like flexibility, know-how and organisation must be taken into account as well. As a general rule, the goals of strategic technology management should be long-term ones aimed at maintaining and strengthening the company's position (SPECHT & MÖHRLE 2002).

3.2 Technology Related Environment and Business Analyses

In order to reach informed strategic decisions, it is vital to procure and evaluate a whole series of information. This entails carrying out not only an analysis of the environment but also internal technology analyses.

External technology analyses start by investigating the global environment. In particular, this includes the influence of and changes to the natural environment, general technological trends, socio-cultural aspects, political and legal developments and the economy. This information tends to be non-specific and points to development trends that impact the company either in its entirety or only in an indirect way. The more specific environment analysis, on the other hand, is more detailed and more specific, and refers to concrete observations of the individual industries or markets operated in by the company or its business units (GELBMANN & VORBACH 2003). Two elements are differentiated here (refer to Fig. 8.2, GERPOTT 2005).

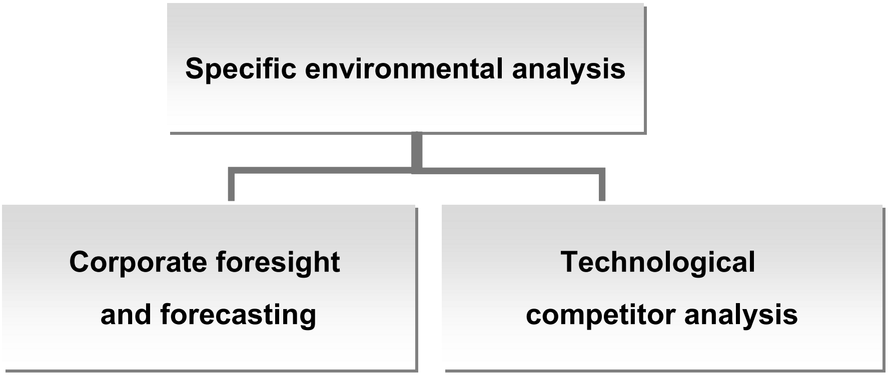

Fig. 8.2: Specific environment analysis

"Weak" signals often represent the only advance warning of long-term technological changes (ANSOFF 1976). The aim of technology foresight and forecasting is to identify these signals at the earliest possible stage and cast light on their development and risk potentials. The technology foresight and forecasting process usually comprises three phases (MIEKE 2006):

- Data collection
- Data analysis
- Data structuring

Technology foresight and forecasting are most likely to succeed if they are seen not as a cogent system but as an iterative learning process (LICHTENTHALER 2003). The first step is concerned with procuring information through patent, document and conjoint analyses, Delphi studies and various other methods. In the next phase, the identified information must be evaluated with the help of portfolio or lifecycle concepts. The resulting data and findings are then structured in the third step. The scenario technique, technology roadmapping and technology agendas are popular instruments for this purpose.

The outcome of technology foresight and forecasting should be to reveal substitution technologies, optimisation potentials for new and established technologies, the limits of existing technologies and the opportunities if technologies are combined – without entering into detail about competitors' specific fields of business (MIEKE 2006, WEHRMEYER et al. 2002).

In contrast to this, the technological competitor analysis focuses on selected companies. The goal is to minimise the risk of being taken by surprise by competitors' technological innovations, while at the same time increasing the company's own room for manoeuvre with regard to counter-measures. In addition, the company can benefit from information about alternative approaches to technology development practised by a competitor but so far not adequately contemplated by itself. Various tasks must be carried out in order to achieve this. First of all, the objects of study must be chosen. This entails deciding which suppliers of products and services to observe and which topics to consider. Information gathering and archival are other typical tasks. This is not always easy because the majority of companies only publish general information, if any, about their current situation, and forecasts or strategy statements are only revealed in exceptional cases. As with technology foresight and forecasting, the final step is to collate and exploit the data recorded. The result of the technological competitor analysis should be to facilitate a decision regarding the procurement and exploitation of external technology, technology protection and recommended actions such as the date of market entry (GERPOTT 2005, VAHS & BURMESTER 2005).

Despite the differences between the procedures employed for technology foresight and forecasting on the one hand and the technological competitor analysis on the other, these two instruments used for the detailed environment analysis are inextricably linked. Not only this, the combination of both elements should pinpoint technological developments at the earliest possible stage, to enable them to be leveraged for the company.

The internal technology analysis, often also referred to as the business analysis, is restricted to an analysis of the company itself and focuses on obtaining an objective picture of the current and future situation. One suitable approach for gaining a clear overview is to examine the company's activities along its value chain. Another effective method of measuring the potentials relevant to the company's competitiveness is to analyse its strengths and weaknesses. As with all studies assigned to the internal technology analysis, three questions are particularly important (GERPOTT 2005, BURGELMAN et al. 2001):

- Which internal resources can the company draw on for technology development and which external technology sources can be leveraged?
- How effective and efficient has the company been in the past at managing its technologies?
- How closely are technological capabilities aligned with competitive strategies?

These questions can be answered by involving company employees and external consultants. Drawing conclusions and making decisions about whether to build up or cut back specific technology development resources are outside the scope of the business analysis.

After analysing the external opportunities and risks as well as the internal strengths and weaknesses, the next step is to collate the information identified. Portfolios are a suitable instrument for presenting the current and future environment and business situations. Strategies for future activities can be derived from the positions and constellations created in this two-dimensional matrix (SMIT & TRIGEORGIS 2006, BULLINGER 1994).

3.3 Determination of the Technology Strategy

The technology strategy can be formulated on the basis of the goals and of the technological environment and business analyses, taking account of the superior corporate strategy. The technology strategy must also be aligned with the strategies of the business units and functional departments, because it describes decisions and actions linked to the development and application of technologies in all parts of the company (SCOTT 2001, METZ 1996). This cross-sectional function is a fundamental characteristic of technology strategies. A technology strategy is generally distinguished by the following four elements (SPATH & RENZ 2007):

- Technology procurement aspects,
- Timing of the invention and the innovation,
- Scale (level) of innovation,
- Technology exploitation aspects.

The strategic direction for developing technological know-how and technological capabilities is determined by specifying and defining these four elements of the technology strategy. The strategy is formed by the totality of the elements (RENZ 2004).

In view of the market dynamics and intense competitive pressure, it is increasingly vital to additionally procure technological know-how by resorting to external resources. However, restricting technology procurement exclusively to sources outside the company is neither possible nor recommended owing to the lack of competitive advantages. The knowledge drain in connection with core competency technologies can ultimately jeopardise the company’s existence. External technology procurement can also be influenced by technical and commercial limitations. The challenge confronting technology management is to achieve the optimal balance between internal and external resources. There are several intermediate forms between in-house development and taking out a licence or buying technology in from outside, which may or may not be suitable depending on the situation. The main modes of cooperation without capital investment are contract research, collective research, virtual companies and strategic alliances. Another alternative is to purchase shares in the external company in order to influence the ongoing development and exploitation of technological results as well as the use of resources for research and development. Mergers, joint ventures and minority or majority interests are typical examples here.

The time element of the technology strategy concerns the timing of the invention and the innovation. Whereas "invention" means the generation of the necessary technical know-how, "innovation" describes the exploitation of a technology in the market for the first time (BULLINGER 1994). Timing is an important issue in both phases, whereby a distinction is made in each case between two basic roles, namely leader and follower. This is an option that only remains open until such time as one company assumes the leadership role. The role of follower is not necessarily a disadvantage, however. A follower incurs lower research and development costs in the invention phase, which means its outlay can still be recovered even with a later market entry date. The follower also has a chance to learn from the leader's research failures and mistakes. Creating a cheaper product imitation or modification that has been optimised for a particular customer are other possible strategies for invention followers. On the other hand, there are also a number of advantages to leadership: early inroads into attractive markets, the option of establishing standards, a longer presence in the marketplace, a temporary supply monopoly, the erection of market entry barriers and a clear lead on the experience curve are only a few of the benefits. Both the leader and the follower roles entail opportunities and risks that must be on a case-by-case basis. It is not possible to provide general recommendations for strategic action regarding the timing of the invention and the innovation.

The scale of innovation describes the technological performance level in relation to the current state of the art. Technological performance tends to be difficult to measure and operationalise. Only two options are therefore differentiated for the sake of simplicity: a "high" technological performance strategy and a "normal" performance strategy. Technology pioneers, in other words companies that pursue a "high" technological performance strategy, occupy a leading position in a specific technology field compared to the typical standard of knowledge in the industry (GERPOTT 2005). They generally invest substantial amounts of money in the active promotion of technical progress by carrying out basic research of their own. However, many companies rather position themselves on the level of the "normal" technological performance strategy, where they concentrate on key or basic technologies. These companies are consequently referred to as "technology participants". Decisions regarding the timing of the invention and the innovation as well as the scale of innovation cannot usually be taken in isolation from one another. They are also fraught with similar problems. When defining a strategy to achieve the envisaged technological performance, it is therefore essential to consider how it interacts with the time aspect of the technology strategy.

High research and development costs in an increasingly fierce competitive environment and ever shorter product and technology lifecycles mean existing technologies must be optimally exploited (BIRKENMEIER 2003). One option is to apply technology within the company to the creation of goods and services. There are often many other possibilities in addition to this classic variant. Collaborative exploitation with partners in the form of spin-offs, strategic alliances, etc. is especially suitable if the aim is to break into additional markets while minimising the risks and the capital expenditure. The companies involved should not be direct competitors, nor should they have already cooperated during the development phase. Exclusively external technology exploitation is another alternative, such as issuing licences or selling technology. Compared to licence agreements, technology sale is a much quicker way for a company to cover its research and development costs. However, by selling, the company relinquishes all rights to use the technology further and as a result could be denied access to future technology potentials (GERPOTT 2005).

3.4 Implementation of the Technology Strategy

After selecting the technology strategy to be pursued, its contents must be transferred to specific, strategy guided actions in the framework of the implementation phase (AL-LAHAM 1997). Thereby, the implementation shall not be regarded as a minor step but, in fact, as an integral part of the strategic technology management (PAVITT 1999). Two basic task complexes are differentiated in the implementation phase (GÖTZE & MIKUS 1999):

- Behaviour focused enforcement
- Function focused implementation

Structural changes are partially unavoidable when the technology strategy is specified. To overcome possible opposition to the strategy and encourage acceptance of strategic decisions on all company levels, it is a good idea to launch suitable programmes of measures. These programmes should support staff during the change process, so that all detailed decisions taken at the operative level are consistent with the technology strategy.

The function focused implementation of strategic decisions in concrete projects and measures does not belong to strategic management but is a task for operative technology management. It is above all important to ensure basic conditions conducive to a certain level of efficiency in operative technology management.

4 Conclusion

The technologies that exist within a company are essential elements for maintaining and strengthening that company's competitiveness and ability to survive. Technical know-how is vital both to manufacture products and to plan and control processes. It should therefore be the endeavour of every company to install systematic technology management. A holistic approach to technology management reveals the relationships between the different levels and integrates individual perspectives to enable all the company's technologies to be profitably exploited. The normative aspects of technology management provide the framework for strategic technology management. The goals that form the basis for the technology strategy are formulated at the normative level. A strategy is a possible way to accomplish goals. The detailed specification and direct implementation of the technology strategy is a task for operative technology management. All decisions reached are transferred to concrete measures and must be taken into account in day-to-day operations. To achieve lasting success, it is advisable to integrate technology management on all levels and to align it with existing processes, resources and structures. Strategic technology management plays a key role here. In addition to helping identify and develop technological trends and potentials, strategic technology management also supports the analysis, customer-focused optimisation and efficient exploitation of existing technologies. Basic decisions regarding the use of technology are likewise taken in the framework of strategic technology management. The importance of strategic technology management will continue to grow in the future because both products and processes are comprised of an ever larger number of dissimilar technological components. The diversity of new knowledge areas such as bioinformatics or micro-sensors offers clear confirmation. The ability to evaluate technical know-how in different disciplines and fields, and reach landmark decisions regarding the use of technology, will increasingly become an existential matter for companies everywhere.

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9 Success with Customer Inspiring Products – Monitoring, Assessment and Design of Perceived Product Quality

Robert Schmitt, Tilo Pfeifer

Nowadays, technical excellence is not enough to enthuse the customer for a product. Absolute freedom from error is a basic requirement, but how can the customer be rendered enthusiastic about future products? The answer to this question lies in the creation of optimal customer-specific products. Perceived quality of a product is constituted by all visual, tactile, acoustic and olfactory impressions. "Perceived Product Quality" adds customer group specific and subjective perceptible characteristics to the basic understanding of quality. Until now, there is no comprehensive systematic approach to close the gap between subjective customer perception and objective product characteristics.

1 Introduction

The global availability and replaceability of products and services lead companies of each industrial sector to search for a unique and distinctive image. In doing so, more and more companies find out that the megatrend called "innovation" on its own is not the key factor for success; only the effective realization of a new, independent product, which is accepted by the market and the customer, assures corporate success (LORENZI 2003). Prosperous product innovation is characterized by fulfilling even latent customer requirements, not only concrete wishes. Through this fulfillment it is possible to enthuse instead of only satisfy the customer. Identification of latent customer wishes at an early stage and transformation of these into product characteristics play a decisive role. Nevertheless it seems that the quality of German products has decreased throughout the last five years. This is confirmed by customer satisfaction surveys concerning German cars competing with products of international manufacturers (SCHMITT & REISSIGER 2006). It is necessary to achieve customer orientation and quality of a new dimension by

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developing a new methodology. For a long time now, quality is more than absence of failure! (PFEIFER 2001)

2 Quality is More than the Absence of Failure: The Aachen Quality Management Model

"In an economic order affected by the market, a company can only be successful in the long run if it profitably provides goods or services that release a potential customer's buying incentive through quality, price and delivery time" (MASING 1999). That maxim for successful companies postulated by Prof. Masing shows the classical, basic understanding of quality: quality is the overlap rate between articulated and implicit customer wishes on the one hand, and the entity of product characteristics (incl. price and delivery time) on the other hand (cp. e.g., DIN 8402, DIN EN ISO 9000). Obtaining an advantage in competition means not only fulfillment of well-known customer requirements, but also arousal and satisfaction of latent wishes. To satisfy as well as enthuse the customer, it is essential to have a positive effect on the customer quality perception beyond fulfillment of requirements. Thus, the optimization of the overlap rate between customer requirements and product characteristics is the main entrepreneurial challenge. Therefore, the entrepreneurial idea has to be established in quality management; from a strictly securing, protective view to responsible tasks, which are approached by quality management in an active and flexible way. To integrate previously disregarded tasks of quality management into a holistic concept for corporate management, the Laboratory of Machine Tools and Production Engineering WZL at RWTH Aachen University developed the Aachen Quality Management Model (Fig. 9.1) (SCHMITT et al. 2007a).

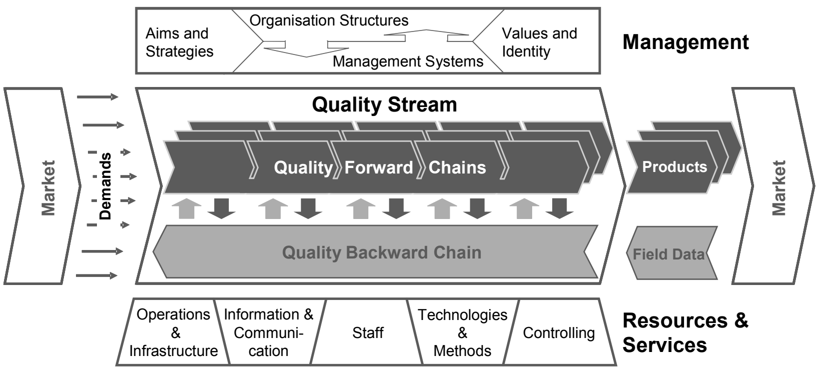

Fig. 9.1: The Aachen Quality Management Model

In this model, the idea of quality is not only limited to products. Quality also refers to potential factors of a company like human resources, technical equipment or management tasks. If quality is understood that way, it is obvious, that quality management has to be established in every position of a company.

The Aachen Quality Management Model spans a holistic regulation framework of quality-related tasks in a company. Within the model, the three core elements (Management, Quality Stream, Resources & Services) build the heuristic framework for operational conversion of quality management and form the top structural level. Each element is subdivided into more characteristic blocks that show concrete set screws for attainment of overall business objectives. Prosperous enterprises recognized that the efficient persecution of quality strategies and targets, a definition of organizational structures following quality aspects as well as the implementation of management systems require a spanning and lasting conduct by a company's top management (SCHMITT & REISSIGER 2006). The implementation of these management tasks requires continuous change management, which sums up all tasks, measures and activities that bring a broad, trans-sectoral change of the contents. Thus, no block of the core element **Management** can stand alone because of the interacting and causal connection between the four blocks (Fig. 9.1).

Resources & Services build the second core element for achievement of business objectives. This element contains the following blocks:

- Equipment & infrastructure (production facilities, measuring systems, test planning, test equipment management, etc.)
- Information & communication (knowledge management, document management, I&C technologies, etc.)
- Staff (qualification, motivation, surveys, etc.)
- Technologies & methods (production methods, working techniques, QM-tools, etc.)
- Controlling (accounting, performance measurement via key data, stage of maturation models, etc.)

The third core element refers to processes and workflows in a company – the **Quality Stream**. The Quality Stream leads from market to market and suits the purpose of increasing product quality or performance and corresponding value-adding processes. The Quality Stream transforms customer requirements into inspiring, customer loyalty creating products. The two structure elements of the quality stream are:

- Quality Forward Chain: proactive, preventive actions
- Quality Backward Chain: corrective, securing actions

The **Quality Forward Chain** consists of all actions, tools and methods to create and secure product quality, performance quality and corresponding value-adding process quality. Particular life cycles give the blocks of the Quality Forward Chain a determining character in relation to time and content. Customer requirements serve as input parameters for the Quality Forward Chain. These requirements are transformed into product characteristics and features. The **Quality Backward Chain** involves among product-independent, continuous use of internal and external data the deduction of corrective, securing quality management actions for products, services or corresponding value-adding processes in the market or in the phase of design. This subsumes internal improvement processes as well as essential field data information, which has to be retrieved and used at the right place in the enterprise. Customer-driven and also technology-driven innovation requires knowledge and distribution about the two Quality Chains to transfer ideas into successful products.

Consequently, the Quality Stream with its two processes, Quality Forward Chain and Quality Backward Chain, is core element and focus of the model. Finally, the Quality Chain is responsible for the existing product and/or service quality perceived by the customer. The following method of resolution can be incorporated into the Quality Forward Chain of the Quality Stream. This method deals with monitoring, assessment and design of the Perceived Product Quality to achieve customer satisfaction.

3 Customer Satisfaction – An Indicator of Quality

Goods and products are exchangeable. Customers nowadays take no significant risk if they change a company or a brand. For this reason, it is a basic intention for a company to establish and assure a permanent regular clientele as the general basis of economic success and long-term growth. Satisfied customers are the key to a stable customer base. Not only the technical aspect highlighted in many cases, but also customer satisfaction must be a quality measure (SCHARNBACHER & KIEFER 1998). In this context, some questions arise: What forms customer satisfaction? How is it created? How important is it for corporate success? How is it linked to the attribute “quality”?

Product quality, customer satisfaction and corporate success are irrevocably connected. Product quality establishes a good corporate reputation. A good reputation provides boundless opportunities. Companies with a lost reputation are often faced with ruin. Only ambitious efforts can connect the corporate name to the attribute “quality” again. Accordingly, customer dissatisfaction is an obvious indicator for “not-quality”. For a company it is five times more expensive to acquire a new customer than to keep a regular customer. Also, 95% of dissatisfied customers will flee from a product with a bad reputation. Only 5% of the customers will articulate an opinion, which gives the company the possibility to improve their product quality. Rather, 95% will migrate silently or harm the companies’ reputation through negative word-of-mouth influence. Statistics show that they share their displeasure with at least 9 (and up to 20) people (SCHNEIDER 2000). What might be the reason for satisfaction or dissatisfaction on the customer’s side? Customers are rarely displeased without any reason and they establish their own criteria for quality in the long run. In most cases, it is products and/or services they bought. Besides the fact that product-specific criteria constitute the dimensions for customer satisfaction, how the product is perceived and assessed by the customer must also be considered. On the one hand, there are economic factors, e.g. running costs; on the other hand, there are quality criteria, which can be divided as objective and subjective. Customers distinguish product-related criteria between hard factors, which are quantifiable (objective quality criteria), and soft factors, which are related to e.g., design or car configuration (subjective quality criteria).

4 Customer Satisfaction – The Different Views on Quality

As aforementioned, product-related quality criteria can be divided into two categories and can be described via objective and subjective quality factors. These quality factors generate two views on product quality and will be under examination below (Fig. 9.2).

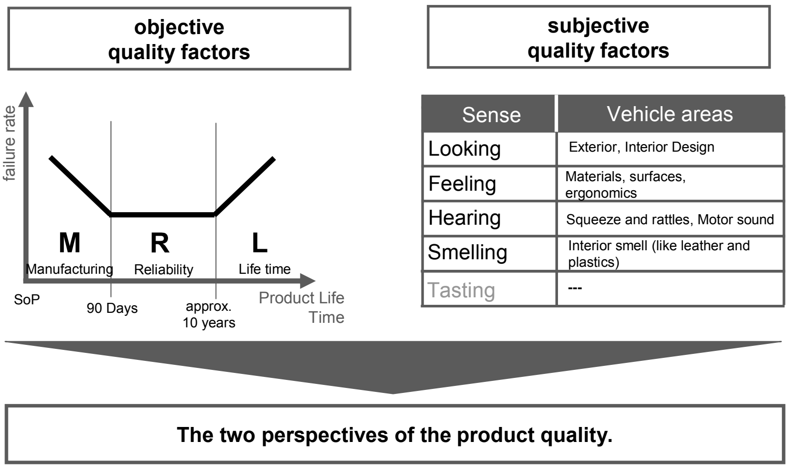

Fig. 9.2: Factors and perspectives of the product quality

Following the Weibull curve in Fig. 9.2 for automobiles, **objective quality factors** can be roughly divided into three categories, described by figures, data and facts. On the basis of the facts, the customer forms an opinion and generates satisfaction. The category "manufacturing" (zero defect manufacturing) shows conformity of the product with the defaults of the product concept (e.g., according to drawings). Inside the automobile industry, failure within the first 90 days usually results from deficiencies in the production process. Cars called "real lemons" are very good examples for deficits in manufacturing. "Reliability" reflects the probability of failure within a certain period of time. The characteristic parameter is the time span between two unwanted incidents (MTBF: Mean Time Between Failures).

"Life time" describes technical as well as economic aspects. Technical durability is reached at the point where the product loses its usefulness and where repairing it makes no sense, e.g., blown bulb. Economical durability ends where the user invests in a new product because of improper repair costs. Here, durability is very proportionate to reliability. Zero defect manufacturing, high reliability and long durability of a product secure the user from a negative experience. These quality categories match traditional concepts of quality assurance – safeguarding of a product's usefulness and absence of failure. Market entry requires possession of that quality type, but these days almost every product is reliable and the advanced level provides no room for differentiation.

Subjective quality factors form an additional quality opinion in the customer's awareness. The understanding of quality perception starts with the simple conclusion that impulses from the outside world have five channels for reaching the human cerebral cortex to become conscious. Perception is possible via: looking, hearing, feeling, smelling and tasting. These perceptions pick up subjective quality factors and define the part of quality requirement that pertains to the products' quality characteristics via the five senses (Fig. 9.2). Perception is influenced by advertising, trends, associations with gained experience and requirements referring to the new product. Therefore, a customer generates wishes on the basis of self-defined grades. These wishes are articulated toward the manufacturer as quality requirements or assumed as expectations. The supplier (manufacturer/contractor) disposes of a product with a certain condition. The condition of a product is neutrally described as the whole of all characteristics and features (PREFI 2002). Not until the customer compares the product condition and own expectations quality characteristics are built. This incidence results in a conclusion about product quality (MASING 1999).

5 Customer Satisfaction – An Emotional Reaction to Quality

As shown, customer satisfaction is an emotional reaction. The customer summarizes the presented objective and subjective quality factors and compares found As-Is components of a product like technical features, design and other characteristics with self-invented To-Be components (requirements). To-Be components contain, as described, experiences or advertising promises that create a certain mindset of expectation. After recording the two components a cognitive comparison process takes place. This consciously as well as unconsciously made cognitive comparison process results in "Perceived Quality" (Fig. 9.3).

A comparison of "To-Be components" and "As-Is components" leads to confirmation or disconfirmation of expectations. The feeling of satisfaction or dissatisfaction results from a valuation of confirmation or disconfirmation. Concerning economic exchange operations, satisfaction or dissatisfaction is an emotional reaction of a customer based on a corporate performance, process, service or product. Customer satisfaction is the outcome of a psychological comparison process between perceived product quality and a customer's expectations, pretensions or intentions (HOMBURG 2001). Simple customer satisfaction can only be a subordinate target. The overall target is achieved if As-Is components of a product exceed requirements and wishes (To-Be). The outcome of this is customer enthusiasm. Not until enthusiasm is attained a company is able to commit the customer to itself via the product. This is how the all-dominated customer loyalty is created (SCHMITT et al. 2007b).

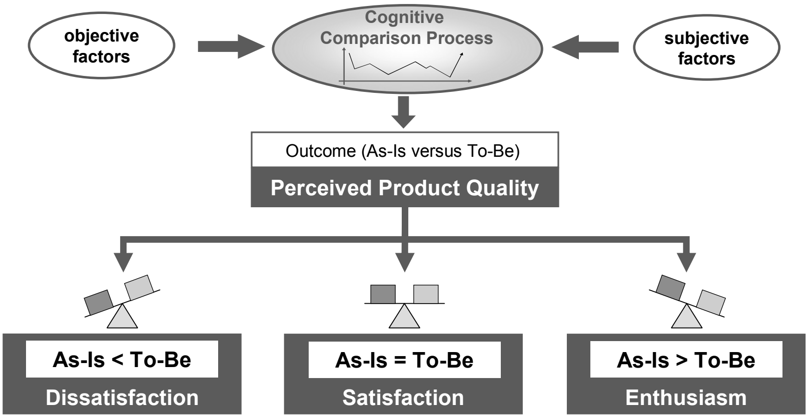

Fig. 9.3: Perceived product quality as a result of a cognitive comparison process

6 The Lever of Success Lies in the Early Stages of the Product Lifecycle

The challenge in developing such a methodology for the improvement of perceived product quality is the simulation of the cognitive comparison process (Fig. 9.3) before the start of production in order to predict product-specific customer opinions in an anticipative way. Hence, customer enthusiasm would be secured before market entry. Intent of the methodology is a survey about subjective customer requirements, opinions and wishes toward a product in order to balance them with objective product characteristics of a prototype.

A conscious design of positive quality perception establishes required business differentiators in today's cut-throat competition. Products have to be designed in a way that covers subjective feelings, expectations and associations in order to create satisfaction or enthusiasm.

Additionally, the Aachen Quality Management Model shows that quality management alone is not able to grasp, analyze or improve perceived product quality in order to create customer satisfaction systematically. Quality management provides very effective and efficient analysis methods and improvement tools, yet these are not sufficient. As previously mentioned, perceived product quality is a result of a cognitive comparison process that combines subjective and objective factors (Fig. 9.3). Subjective features (wishes, expectations, requirements) will be compared with objective product features (figures, data, facts) so that reconciliation can occur. For the collection of customer characteristics (To-Be components), existing QM tools can be used, e.g., Kano method. Product characteristics (As-Is components) will be recorded with a competent measurement instrumentation. Gained information supports the comparison process that provides perceived product quality in a predictive way. For the existing issue, the integration of metrology and quality management is very reasonable.

Figure 9.4 shows the point in the product life cycle where such a future QM-method must be installed in order to improve perceived product quality. More precisely, this point is: In the product realization phase, where the "Voice of the Customer" is transformed into a first prototype. The black box represents the cognitive comparison process, which is supposed to be simulated by the method presented here and described in the following.

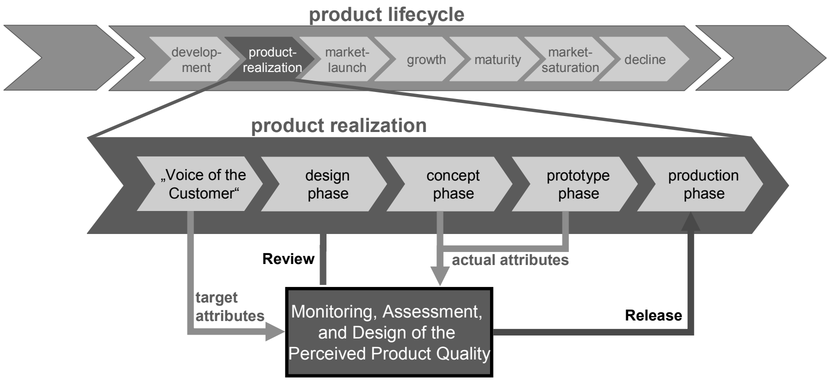

Fig. 9.4: Companies have to act in the early stages of the product lifecycle

Consistency of actual attributes (concept and prototype data) and target attributes initiates product transition to the stage of production. If the black box generates deviation, the product has to be revised in the design phase to achieve full attribute overlap in the following steps.

After identification of method combination and field of application, the black box shown in Fig. 9.4 will be developed. A method for the improvement of perceived product quality will be conceived as well.

7 A Multidisciplinary Approach to Customer Satisfaction: Perceived Product Quality Forecast

A method for systematic improvement of perceived product quality is based upon an explanatory model designed by the WZL. The model allows the illustration of complex coherences between subjective and objective customer and product characteristics and consists of To-Be components of customer characteristics as well as As-Is components of product characteristics (Fig. 9.5).

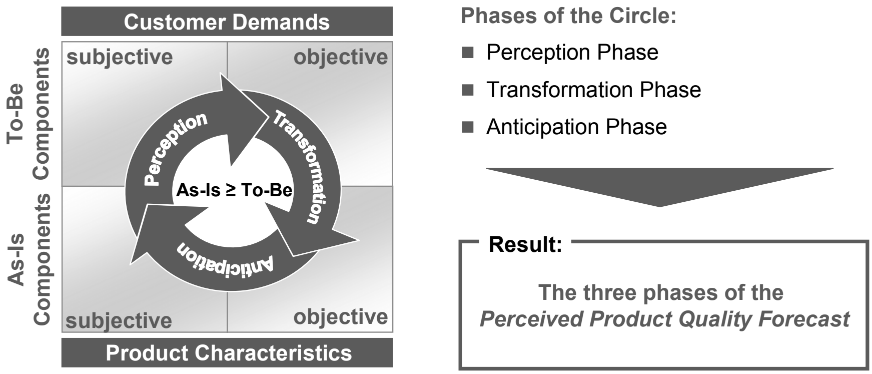

Fig. 9.5: Explanatory model about quality perception of products

Every sector is characterized by subjective as well as objective characteristics and four configuration levels. A continuous To-Be/As-Is comparison, shown in the centre of the model, checks the extent of overlap of characteristics. The goal must be that the As-Is components at least be on par with the To-Be components.

In the following, the four components of the explanatory model are briefly characterized. Afterwards, the phases of the method for product optimization will be derived:

Subjective To-Be components of customer anticipation:

- personal needs and previous experience
- direct third party communication (e.g., media, style trends)
- indirect communication (e.g., word-of-mouth influence)

Objective To-Be components of customer anticipation:

- quantifiable characteristics
- features and control elements
- advertising promises and competitive products

Objective As-Is components of the product (characterizing, technical features):

- workmanship
- reliability
- durability

Subjective As-Is components of the product (perception via cognition senses):

- design
- comfort and interior
- emotions, feelings and amusement

The four components help illustrate the two views on product quality (Fig. 9.2) and also assist with explaining the causal direction. The loop in the middle summarizes the different perspectives and also continuously balances the four components.

Task of the loop is the objectification of subjective characteristics and transaction of a To-Be/As-Is comparison between the characteristics. This loop consists of three phases: perception, transformation and anticipation, which together build the WZL method called Perceived Product Quality Forecast. This method allows a forecast of product quality perception in the early stages of product development. A definition of the "Perceived Product Quality Forecast" method is mentioned below and the three phases are explained.

7.1 Perception Phase (Phase 1)

The first phase deals with the gathering of all quality features that create the two views on product quality. As mentioned, the perceived product quality consists of subjective and objective demands, which can be divided into customer- and product-specific characteristics. For the **sampling of customer characteristics**, established QM methods will be used: in particular, the Kano method, Design of Experiments (DoE) and customer clinics. The three approaches will be combined and set in a chronological order. The Kano method records customer requirements toward new products or improvements and clusters them into basis, performance and enthusiasm features. The following DoE systematically prepares the next step – the use of customer clinics. The methodical procedure of customer clinics provides the opportunity for the conception and realization of large surveys concerning customer acceptance. The main problem in performing customer clinics in the traditional way is the too-specific customer group orientation. Another drawback is the incalculable profit of customer clinics. The customers within the clinics vote for a product and give their acceptance to a product, but this only in a qualitative way: good or not good. It is not possible to get a conclusion regarding the way in which to optimize the product. The customers are not able to give a quantitative statement. They are not specialists and do not know the effects and interactions of the several product characteristics. By the use of DoE it is possible to generate experimental designs based on the results of the Kano method. Thus, a systematical survey in the customer clinic is possible. The use and combination of these three quality management methods ensure that essential product change details will be collected and assessed.

Capable metrology will be used for the **sampling of product characteristics**. For the different senses (Fig. 9.2), specific metrologies can be assigned to gather product characteristics. Therefore, the characteristics of the sense “feeling” can be collected by haptic measurements such as linear force-displacement characteristics via rotary switches or like a tactile measurement for the inspection of gaps. In the scope of the sense “looking”, optical measurements (measurement of color gradient of the materials) can be used to obtain the necessary data. For the sense “hearing”, acoustic measurements such as the Noise Vibration Harshness (NVH) test in the interior of vehicles are required. The use of metrology is responsible for the objectivity and assessment of the gathered product characteristics. The last step of the first phase involves the archiving of the collected data. Therefore, a perception database has to be installed that must be continuously updated. The database is the starting point of future innovative products.

The outcome of the first phase is a holistic and complete perception database that includes all gathered customer and product characteristics.

7.2 Transformation Phase (Phase 2)

In the second phase of the presented WZL approach, the collected data will be analyzed and assessed. This means that the customer clinic information (customer characteristics) will be systematically analyzed and compared with the corresponding product characteristics gathered through metrology. Thus, effects and interactions of the characteristics can be determined and design rules are derivable – design rules that will present the framework for the next product type, respectively, for new future innovative products. The goal of these enterprise- and product-specific design rules is to predict and to ensure customer enthusiasm.

The analysis and interpretation of the effects between the customer and product characteristics shall be made, for example, via statistical methods such as correlation analysis. The direct alignment and comparison of specific technical characteristics with previously collected customer demands will be used for future product optimization and development. In this way, enterprises generate information about the interrelationship of customer expectations and the realized technical product characteristics. The qualitative statements made by the customers in the clinics can be systematically led back to the technical realization. Relationships between the characteristics become obvious. General design rules can be generated by using the determined relationships. With these general rules and with the current knowledge about the products and the customer demands, each enterprise has to develop its own special custom-made design rules.

The outcome of this second phase is an enterprise-specific catalogue with rules for developing and designing products before the start of production. These design rules ensure a positive perception of the products with the goal of customer enthusiasm. A prediction of customer satisfaction is given.

7.3 Anticipation Phase (Phase 3)

The last phase of the Perceived Product Quality Forecast includes a simulation of the product designed with predetermined design rules. Database information allows an anticipated illustration of customer enthusiasm and serial production can be initiated. If the simulation shows customer dissatisfaction, the gathered knowledge must flow back to the design phase of the realization process. Another subsequent characterization check is necessary. The result of the third phase is a simulation of the anticipated product configuration in order to predict customer enthusiasm. After passing all three phases of the Perceived Product Quality Forecast, a targeted improvement of perceived product quality is possible.

8 Conclusion

This article shows that systematic improvement of perceived product quality is possible via Perceived Product Quality Forecast, a method currently under development at the WZL. This method offers the opportunity to sample information about expected, actual and future perceived quality and to provide the data to product development. Integration of the customer opinion at the stage of development and production reduces development risks and increases the chances of success. It is guaranteed that the first draft of a product gains the customer's best perception. This conscious design of quality perception creates the required competitive differentiator in today's cut-throat competition through predictable customer enthusiasm.

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10 Pattern Languages to Create a Holistic Methodology for Product Development and to Derive Enterprise-Specific Engineering Guidelines

Jörg Feldhusen, Frederik Bungert

1 Introduction

After several decades of ongoing globalization and keen competition, enterprises find themselves faced with increasing market demands on individual, customized solutions. At the same time, global markets require shorter product creation processes at lower expenses in order to remain competitive. Due to this fact the technical innovation proceeds and leads to more complex products and processes as well as an unmanageable portfolio of individual solutions.

To cope with those challenges engineers need to have appropriate skills and knowledge at their disposal. A huge amount of knowledge has been gained in the context of product development. This knowledge is only loosely connected and lacks integration so far. The aim of applying pattern languages to product development, especially engineering design and PLM (Product Lifecycle Management) is to develop a cohesive methodology, which integrates current archetypal knowledge and makes it continuously applicable during the entire product lifecycle.

2 Methodologies Within Product Development

According to Pahl/Beitz, a methodology is generally defined as systematic proceeding comprising several methods and utilities (PAHL et al. 2007). Furthermore, a method denotes a systematic proceeding to reach a certain objective (PAHL et al. 2007). Accordingly, a methodology can be seen as a system of methods aiming at accomplishing tasks of a certain class (NEUHAUSEN 2001). A system is defined as a target-oriented unit of interrelated entities (here: methods) (BROCKHAUS 2007).

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A methodology for engineering design is a precondition to rationalize the engineering design process. Accordingly, a methodology in general increases the efficiency of the derived activities in terms of a systematic transfer of common application knowledge to application scenarios. Furthermore, the application of a methodology advances targeted acting and thus increases the effectiveness of those activities derived from a methodology.

A couple of commonly applied engineering design methodologies have been developed, such as the concept of Systematic Engineering Design (SED) by Pahl/Beitz (PAHL et al. 2007) and the methodology by KOLLER (1998), both developed in Germany and subsumed within the norm VDI 2221 (VDI-Richtlinie 2221, 1993), or the Theory of Inventive Problem Solving (TRIZ/TIPS) by ALTSCHULLER (1998) originating from the former USSR. A common ground of those approaches is that their focus is narrowed to the innovation process of mechanical products.

Besides engineering design, several methodologies within the domain of product development have been developed. Engineering disciplines, such as electrical design, software development, industrial design, service development or production and maintenance planning, directly contribute to the development of a product. Many of these disciplines provide a particular methodology.

Over the past years the idea of PLM (Product Lifecycle Management), which emerged in about 2001 (STARK 2004), has been disseminated in the engineering community. PLM is defined as a knowledge-based enterprise strategy for all processes and methods regarding the development of products from the product idea to recycling (PAHL et al. 2007). Nowadays, the methods of PLM are widely accepted and commonly applied in industry.

To increase the efficiency and effectiveness of product development beyond existing methodologies, a holistic product development methodology covering the development of the entire product portfolio of a company and moreover the entire lifecycle of each product concerning material, data as well as information is required. Although each of the engineering disciplines mentioned above focuses on a certain aspect defining the product to be developed, the related methodologies lack integration so far. The PLM-methods are not interrelated to each other. Hence, even a methodology for PLM does not exist. Both the integration of all engineering methodologies and the existence of an integrated PLM-methodology are basic prerequisites for a holistic product development methodology.

3 Pattern Languages

Pattern Languages were originally invented by Christopher Alexander (ALEXANDER et al. 1975, 1977; ALEXANDER 1979) in the 70s. They were first applied in civil and architectural design to capture archetypal design knowledge and to communicate the according solutions with customers. In 1987, this approach was initially taken up by BECK and CUNNINGHAM (1987) in line with an experiment to make object oriented software concepts understandable for application experts without adequate programming knowledge. Consequently, Pattern Languages have been commonly applied during the last decade in the software community. By now, they have gained a strong influence on many fields within computer science, especially software engineering and programming headed by the definitive books by GAMMA et al. (1995), COPLIEN and SCHMIDT (1995), VLISSIDES et al. (1996) and BUSCHMANN et al. (1996), which are representative for a huge number of further contributions, as well as human-computer-interaction (HCI) design pioneered by BORCHERS (2002). Apart from software development, a couple of Pattern Languages focuses on business issues. Furthermore, in educational science Pattern Languages have been developed under the umbrella of the Pedagogical Pattern Project (http://www.pedagogicalpatterns.org). Even Pattern Languages about writing Pattern Languages exist.

The central idea behind Pattern Languages is that, due to complexity, humans have evolved archetypal concepts, which solve recurrent problems. These concepts are called Patterns. As a constituent of a Pattern Language each Pattern describes the application-invariant properties of a solution (archetypal solution) for a recurring problem. Concrete solutions for the recurring problem emerging in a certain context can be directly derived from such an archetypal solution by establishing a reference to the context.

No pattern is a stand-alone entity. Instead, the references to supporting patterns, (constituting patterns) constitute a hierarchical structure (precise: a semilattice; FELDHUSEN & BUNGERT 2007a-d) comprising all patterns of a Pattern Language. Each pattern taken from a Pattern Language is the root-pattern of a smaller semilattice constituting also a Pattern Language (a sub-language; FELDHUSEN & BUNGERT 2007b). A Pattern Language is in turn constituted by such sub-languages.

The patterns (apart from top-level pattern) are embedded into larger patterns, surrounded by patterns of the same size and completed by smaller "supporting" patterns which are embedded in it (ALEXANDER et al. 1977).

For convenience and clarity all patterns within a pattern language have a uniform format and structure. The structure of the original patterns by Alexander is constituted by a set of content types (ALEXANDER et al. 1977), which can be found with only minor amendments in most other Patterns Languages:

- The unique and descriptive *name* of the pattern
- A *plain picture* illustrating the essence of the pattern
- The *initial context* in which the pattern can be applied, represented by larger patterns
- Conflicting forces constituting a recurring *problem* to be solved by applying the pattern
- The *body* delineating a transition from the problem to the subsequent solution and providing empirical background
- An archetypal *solution* to the problem
- A *detailed illustration* visualizing the solution

- The *resulting context* emerging from the initial context after applying the solution, represented by smaller patterns

Apart from software development, in the area of product development pattern languages have not been considerably applied yet. The domains described above, in which Pattern Languages have proven to be expedient, are though similar in many respects to several sub-disciplines of product development. This gives strong evidence for Pattern Languages to provide a similar benefit when applied within product development.

4 A Pattern-Based PLM-Methodology

A PLM-methodology is the key to developing a holistic product development methodology postulated in Sect. 2. PLM provides integrating functionalities within product development (Fig. 10.1). On the one hand, PLM is related to the superordinate area of business economics. Since product development is not an end in itself, it is integrated into an enterprise context in terms of operational business strategies and objectives to be reached by PLM. On the other hand, PLM integrates subordinate operational disciplines contributing to the material lifecycle, the data lifecycle and the information lifecycle of a product. Besides engineering design and industrial design, marketing, manufacturing planning, service planning as well as the IT are among those disciplines.

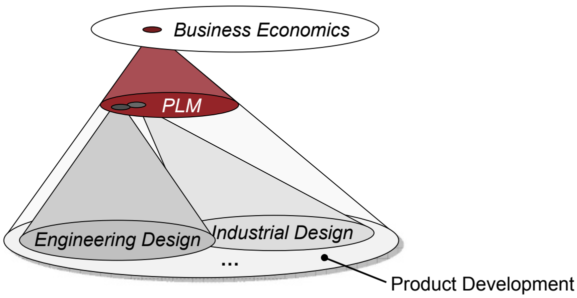

Fig. 10.1: Interrelations of PLM within product development

Since a methodology is defined as a system of methods, explicit target-oriented interrelations between the methods are required (Sect. 2). Assumably, the insufficient methodological pervasion of product development and especially PLM originates from a lacking unambiguous chronological order between particular PLM-methods (Fig. 10.2, left). Although each application of PLM-methods results in a distinct temporal order of those methods, its actual sequence differs between application scenarios and hence is not unambiguous.

The thesis stated above concerning the lack of methodological pervasion of product development is corroborated by the actual chronological structure of current methodologies (Sect. 2). Within those methodologies, the methods are related to each other by a process model defining an unambiguous sequence of application. Figure 10.3 delineates the emergence of a chronological order within engineering design as an example. In line with a certain design step *n* a method *n* is applied to transfer the product data holding state *n* into the subsequent state *n+1*. These product data constitute a computer interpretable product model. Hence, the transformation of the product data comes along with a transformation of the product model *n* into a product model *n+1*. In case of *N* steps the progression (method *1*, …, method *N*) describes the actual design process (in which particular methods due to branches or loops may be comprised several times or even not at all).

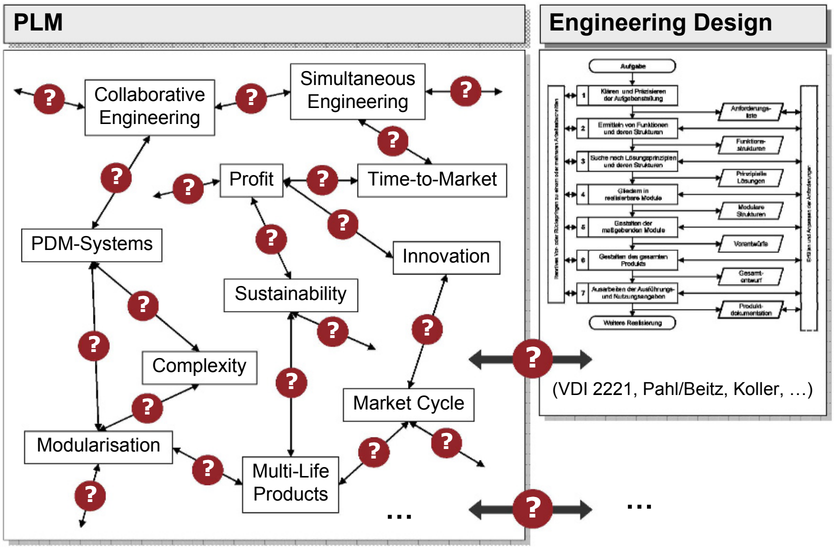

Fig. 10.2: Comparison of PLM-methods and engineering design methodology

By dint of the relations defined by the transformations of the product data and associated models described above possible application sequences of the methods are determined. Certain classes of such an application sequence can be subsumed by an abstract process model. Accordingly, not only prescriptive-normative methodologies subsumed by the common product development process of the VDI 2221 (Fig. 10.2, right), but also contradiction-oriented methodologies, such as the TRIZ and its variants with the ARIZ-process (ALTSCHULLER 1998), are based on a (varyingly detailed) process model, i.e. a model of chronological order between the associated methods.

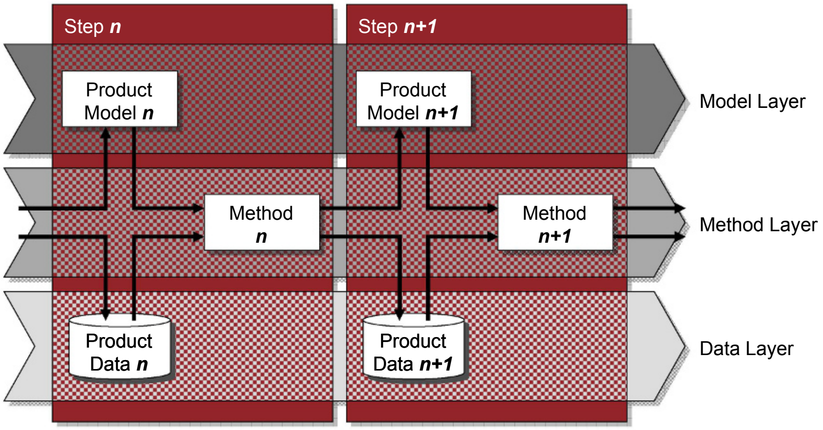

Fig. 10.3: A common base framework of the engineering design process

Pattern Languages provide a solution to the problem concerning the creation of a PLM-methodology described above. Analogue to Figure a Pattern Language provides a base framework to develop an integrating PLM-methodology. The solution of the recurring problem quoted by a pattern can be seen as an objective. Furthermore, the associated archetypal solution can be interpreted as a systematic proceeding to reach that objective. Accordingly, each pattern constitutes a method (though many methods in turn are not a pattern). Since patterns are interrelated to each other a Pattern Language can be seen as a system of methods. Due to the hierarchical structure of patterns, each supporting the solution of a superordinate pattern respectively, all patterns of a Pattern Language directly or indirectly support the problem stated by the root-pattern as common target. In conclusion, subject to the definition of methodology proposed in Sect. 2 each Pattern Language is a methodology.

The references to supporting patterns constituting a Pattern Language are based on logical dependencies between initial solutions and emerging problems and thus do not rely on any temporal sequence. This makes Pattern Languages expedient to be applied to PLM as a framework to interrelate PLM-methods in terms of patterns resulting in a PLM-methodology.

Similar to engineering design depicted in Fig. 10.3, the temporal dependencies underlying the miscellaneous methodologies delineated in Sect. 2 can be traced back to logical dependencies between methods. Hence, the mentioned methodologies can be couched in terms of a Pattern Language. Several approaches to affiliate Pattern Languages as sub-languages into a more comprehensive Pattern Language are available (FELDHUSEN & BUNGERT 2007). This makes Pattern Languages even expedient to establish a holistic methodology for product development based on a PLM-methodology (Fig. 10.1), which integrates several methodologies related to product development. Corresponding approaches have been proposed by FELDHUSEN & BUNGERT (2007a,b,c,d, 2008).

5 Deriving Engineering Guidelines for Industrial Application

Each methodology, and in particular the methodology outlined in Sect. 4, yields an added value per se when applied in practice. Moreover, the benefit gained from the pattern concept can be further increased by enterprise-specific amendments. Such an amendment, which is based on patterns individualized in terms of relativization of archetypes, solves problems typically occurring in line with the creation of conventional engineering guidelines. Those problems trace back to the creation of a primary index structure, a dense index structure which determines the physical order of the content elements (SCHNEIDER 2004).

Several structures (such as function, design, or manufacturing-oriented structures) are available when creating a primary index structure. Due to the different preferences of the users this creates serious potential for conflicts.

In practice, a type of index structure leading to a sparse in stead of a dense index is often selected. Although such a structure may be advantageous from a technical point of view it excepts several contents from being accessed.

A further problem arises in line with the composition of the primary index structure subject to a certain context graph (Fig. 10.4, left). To provide random access the context graphs has to be transferred to a tree structure. Depending on the actual choice of the root node not all contexts are covered (Fig. 10.4, right).

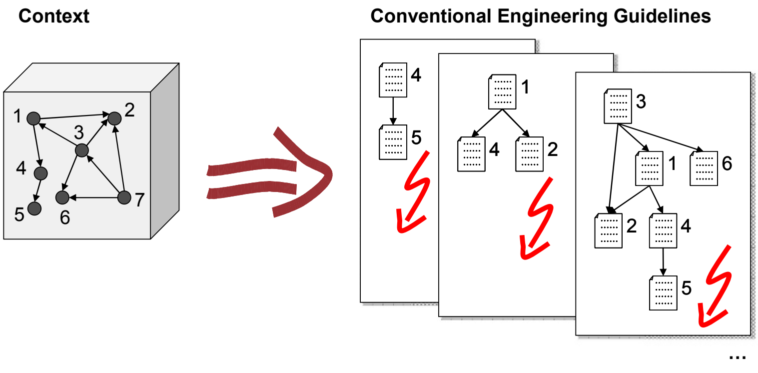

Fig. 10.4: Creation of a primary index structure for conventional engineering guidelines

Pattern Languages are an approach to solve the problems discussed above. However, the concept of archetypal solutions conflicts with the enterprise-specific representation of knowledge. The adaptation of the Pattern-approach to concrete application scenarios requires an enterprise- or employee-specific individualization of archetypes in terms of a successive relativization.

Although an archetype by definition is independent from specific application scenarios and temporal restrictions, the reference character of an archetype corresponds to a certain domain. This actually means a temporal as well as a logical relativization of the universal validity of archetypes.

Pursuing relativization of archetypes leads to an increased individualization, i.e. restriction of the area of validity. At the same time, more and more concepts restricted to a certain scope – especially enterprise-specific concepts (FELDHUSEN & BUNGERT 2007b) – can be interpreted as archetypes. Analogous considerations apply for the set of valid archetypes from employees' or groups' of employees views (FELDHUSEN & BUNGERT 2007b).

Whilst the basic knowledge of each employee (should) comprise the non-relativized archetypes, enterprise-specific archetypes constitute the specific competitive advantage of an enterprise. Employee-specific archetypes in turn represent a potential to be tapped. This raises the need for a concept to document and disseminate archetypes of arbitrary level of individualization.

A level-concept based on the approach to individualize archetypes delineated above is expedient to amend the original Pattern-approach in a way that beyond generic archetypal solution knowledge even enterprise- and employee-specific archetypal solution knowledge can be integrated into pattern-based engineering guidelines (FELDHUSEN & BUNGERT 2007d). This enables the solution of problems concerning the creation of the primary index structure of conventional engineering guidelines delineated above.

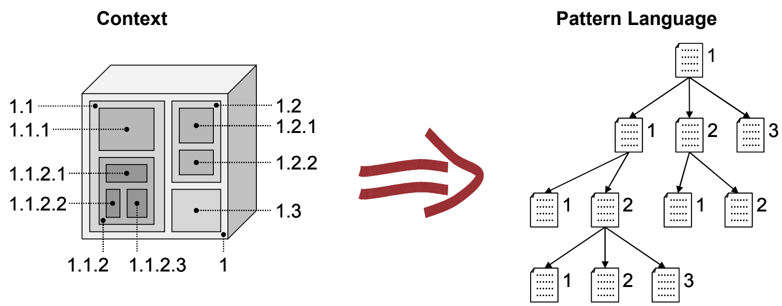

Fig. 10.5: Deriving the structure of a Pattern Language

Each Pattern Language constitutes a primary index structure: On the one hand, the constitutional references of a Pattern Language and the consistent structure of each pattern define the physical order of the content. On the other hand, a Pattern Language defines a dense index structure. This is due to the hierarchical structure of a Pattern Language and the nested initial and resulting contexts of the patterns.

The structure of pattern-based engineering guidelines is initially created in top-down-direction based on a most comprehensive context and an associated root-pattern. This proceeding corresponds to an "unfolding" of context clusters nested into each other (Fig. 10.5, left) resulting in a "natural order" of the content elements (Fig. 10.5, right). Contrary to the creation of a primary index structure based on a context graph (see above), a root node (here: root pattern) is unambiguously determined by the most comprehensive context. This obviates the problems occurring in line with the transfer of context graph into an index structure (Fig. 10.4).

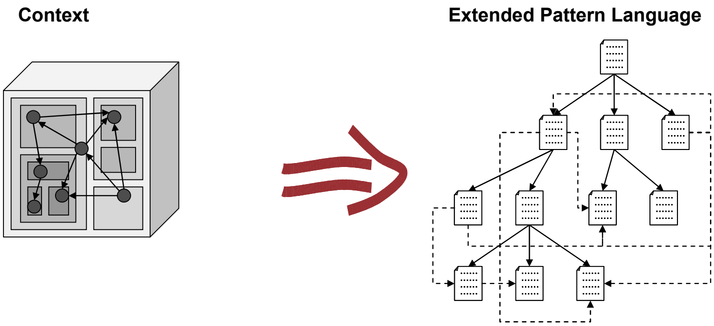

Fig. 10.6: Deriving the structure of a Pattern Language extended by secondary references

Non solution-oriented relations between contexts (e.g. function-, design-, manufacturing-, module-specific, or chronological; Fig. 10.4, left) can be represented in terms of so called secondary reference provided by the pattern concept and integrated into patterns-based engineering guidelines (Fig. 10.6). This actually enables the integration of different kinds of structures which exclude each other in case of conventional engineering guidelines and hence facilitates an enterprise to simultaneously address heterogeneous users' requirements.

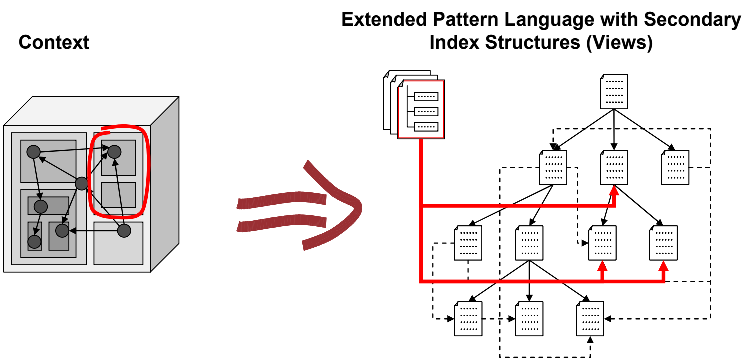

Fig. 10.7: Secondary index structures to realise views specific to users- or user groups

Based on a previously existing primary index structure, pattern based engineering guidelines can be supplemented by additional secondary (i.e. potentially sparse) index structures (views, Fig. 10.7). This enables, for example, providing users or user groups with individualized views by dint of the exclusive representation of particular context cluster or the conjunction of content related to miscellaneous context cluster. Especially, the problem of sparse, but from a technical point of view advantageous index structures can be solved by realising such structures by dint of views.

6 Conclusion

Pattern Languages provide great potential for a methodological "refurbishment" of product development knowledge. A Pattern Language can be applied as a framework to develop a PLM-Methodology and beyond, create an integrative holistic methodology for product development. Furthermore, a relativization of archetypes enterprise-specific engineering guidelines can be developed applying Pattern Languages. This solves the problems typically occurring in line with primary index structures of conventional engineering guidelines (different kinds of structures available; from a technical point of view advantageous, but sparse indices; inappropriate choice of the root).

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11 Reference Models – A Basis for Designing Efficient Technical Services

Günther Schuh, Volker Stich, Gerhard Gudergan

1 Introduction

With the Aachen PPC model and the reference models of service and maintenance, the FIR has set standards in the past which provide the basis for an efficient processing of orders in both production and services within manufacturing industries and maintenance. In the course of advancing those reference models efficient transaction of business processes in production and service has reached a state that is essential for customer oriented and efficient transaction of processes today.

Due to the increasing application of IT which took place in production planning and control beginning in the 80s, development of so called reference models became more significant. During this period, the development of PPC-reference models created a basis for effectively selecting appropriate IT-systems as well as improving PPC-systems and developing new PP-concepts (LUCZAK & EVERSHEIM 1998, SCHUH 2007). This continuing development includes processes within interfaces between companies at an increasing degree due to increasing networking of companies in global supply chains. The same applies to all technical services. Today no company can afford to conduct its services without accurate planning and IT-support.

Subject of this paper is the description of a reference model for technical services. The reference model based on the research of KALLENBERG (2002) has been adjusted and considerably extended. It contributes to the closure of existing "modeling gaps" concerning technical services at interfaces between service companies and their customers – the manufacturing companies. In this paper, the gap as described above is closed from a scientific point of view. For practical application this paper provides a means of assistance for design of structures and processes.

After initially explaining the motivation for developing the reference model an overview of the designing process will be given. Following this, the focus will be shifted on outlining the reference model's structure. Finally, a forecast concerning

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additional applications and future development of the reference model will be given.

2 Motivation, Classification and Target of Developing a Reference Model for Technical Services

Services in their diversity play an important role within economy as whole. They are intrinsically tied to manufacturing industries. However, designing service oriented companies, upgrading industrial products by adding services and even a service oriented redesign of products are difficult processes which pose a challenge to skilled employees as well as executives, in both a practical and a methodical manner due to the characteristics of service production. Costumer integration is a characteristic trait separating services from the production of physical products. Consequential the integration of technical services with customer production poses the special challenge that results from this characteristic. Because of that the model presented in this paper is focused on that issue. For example to ensure high quality services need to be seamlessly interlocked with customers' processes to avoid unscheduled downtimes. The reference model presented in this paper is intended as a tool for practical application to prepare practitioners for handling these challenges.

Because of the size and heterogeneity of the service sector, developing a reference model that includes all possible services is neither feasible nor does it make much sense. A practical model needs to be adjusted to the individual characteristics of the different subsectors within service sector.

So called company oriented services have prominent importance. They form the major economic sector in the European Union. About 55 million people or nearly 55% of all employees of the market-determined part of the European economy are employed in this sector. Excluding financial services, company oriented services are the most important sector in European economy, employing 53% of all employees. Whereas manufacturing industry includes 29% of all employees (about 29 million people). An average of 54% of the entire creation of value is generated by company-oriented services, whereas only 34% are generated in the manufacturing industry.

Considering the special meaning of services the reference model as presented in this paper focuses on services that are provided as inputs for companies (industry and other service providers) and that affect immediately their competitiveness. In the following, these services according to the current classification of this economic sector by the European Commission will be collectively referred to "company-related services".

In the specialist literature referring to service management company-related services are embraced by the term "investive services". According to HOMBURG and GARBE (1996) services can be divided into consumptive and investive services referring to consumer orientation. Consumptive services are demanded by end consumers, investive services are demanded by organizations and companies. Referring to provider orientation investive services can be divided into industrial services and pure investive services. Industrial services are services that are provided by manufacturing companies. Pure investive services are provided by service providers. If services are demanded by companies the term "investive services" is the equivalent of "company-related services".

Referring to a broader focusing that considers requirements of branches and companies the reference model should also orientate to the classification of economic branches according to NACE. Services for companies (NACE 70–74) can be divided into two subcategories: (1) "knowledge intensive services" like IT-advice, consulting, R&D-services and advertisement and (2) "operative services" like cleaning and maintenance of buildings, inventory and transportation means as well as all value-added services like repair, i.e. after-sales-services.

Within the reference model as presented in this paper the second group will be collectively referred to "technical services for companies" or in short "technical services".

In spite of the macroeconomic importance of technical services many of service providers have extensive problems with designing and managing their services. Lack of companies' competencies and experiences in structured designing and developing the service business are seen as fundamental reasons for these problems. While tasks of strategy development are increasingly discussed in the market-oriented research during the last years comparable reference and means for an operative implementation of new service concepts are still lacking.

Because of the value that can be achieved by application of reference models they became an important mean for operative realization of new organizational concepts and IT-concepts in manufacturing physical products. Comparable approaches are lacking in the technical services sector. Particularly approaches that are aimed at a seamless integration of technical services in customer's production processes are lacking.

The reference model as presented in this paper aimed at closing existing "modeling gaps" in active company models referring to integration of technical services into production processes. Previous model design aimed at assisting with a model-based design of technical services focusing planning, initiation and realization of technical services. Development of the model primarily focuses at a synchronous structure of production and an implementation of technical services at the interface to production synchronized with production. Furthermore the model provides applications for reorganizing existing structures as well as applications for choosing appropriate IT-solutions for technical services. Therewith companies should be enabled to determine requirements concerning process design and choose appropriate IT-solutions accordingly.

3 Overview of the Designing Process of the Reference Model

According to the "reference modeling approach" developed by SCHÜTTE (1998) the reference model has been designed methodically.

Among use of desk research methods practical users have been integrated closely into the development and evaluation process by conducting written interviews, expert interviews, workshops and case studies in companies. Considering challenges as presented above the project "Innovation, Coordination and Collaboration in Service Driven Manufacturing Supply Chains" (InCoCo-S) has been chosen and funded by European Commission to develop a reference model for collaboration between service companies and manufacturing companies within a research project between twelve industrial companies and five research institutes. The InCoCo-S reference model (IRM) that has been developed by this research project enables optimization and further development of performance processes of production-related services as well as integration of service processes into manufacturing supply chains. The project has been organized by the FIR. The FIR is responsible for merging research results and extracting the reference model for technical services accordingly.

4 The Reference Model for Technical Services

The IRM has been developed and evaluated for five important industrial services: maintenance and repairs, quality check, modernization of machines, logistics and packing services. The development of the reference model starts from the SCOR-model that has been developed for production and design of supply chains worldwide. By this approach compatibility with manufacturer's business processes should be ensured and a consistent and customer-oriented service performance definition should be achieved. The IRM as well as SCOR are characterized by a hierarchically structure. On first level superior activities are defined in terms of generic process steps. On second level those activities are refined into specific application areas of technical services (e.g., maintenance). Service provider processes concerning activities as defined in first and second level (e.g., service contract negotiations) are characterized in detail on third level.

Concerning production chain the SCOR model is benchmark for designing the reference model. Furthermore the service reference model by KALLENBERG (2002) as shown in Fig. 11.1 is basis for the development of the current model. The service reference model by Kallenberg has been broadly revised and enlarged as shown in the following. Particularly elements of core functions of order processing as well as parts of cross divisional functions have been regarded.

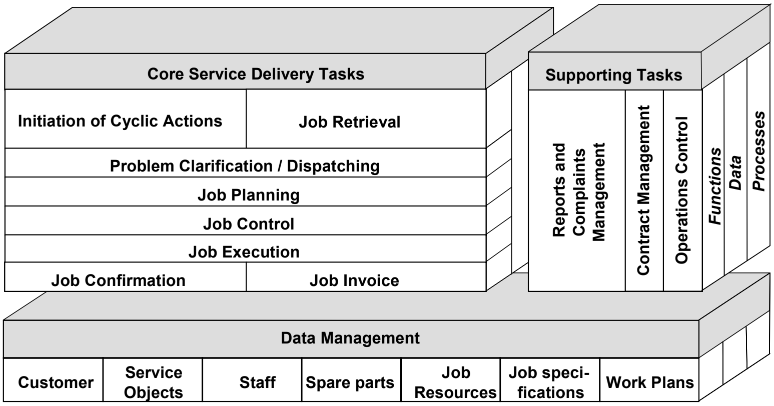

Fig. 11.1: Service reference model by KALLENBERG (2002)

The service reference model by Kallenberg has been considerably enlarged. The IRM differentiates between basic activities “plan”, “adapt”, “build” and “operate” (Fig. 11.2). The superior reference framework for this model is established by these activities. “Plan” includes all activities that are required for preparation of “adapt”, “build” and “operate”. “Adapt” embraces all process steps from customer inquiry to conclusion of contract. Process steps that prepare service provision at customer site are defined as activities referring to “build”. “Operate” includes all activities that take place within the service provision. These activities are based on contents of the reference model by Kallenberg.

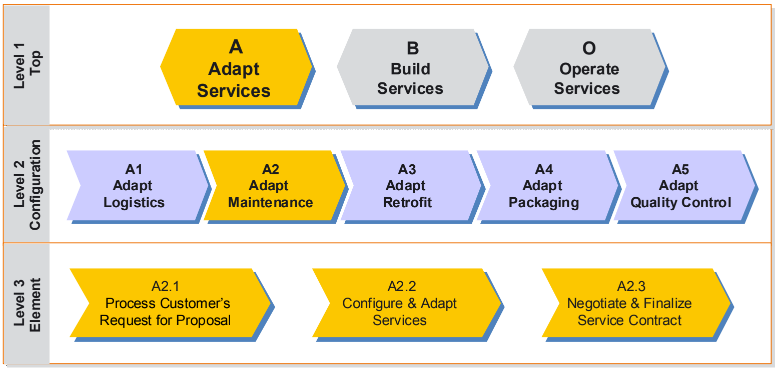

Fig. 11.2: Structure of the reference model for technical services (IRM)

On third level each process step is described in detail in form of a structured process element (Fig. 11.3). These structured elements include the description of process step, defined inputs and outputs as well as performance measures and best practices. Interdependencies with upstream and downstream processes are shown by inputs and outputs. Thus service provider is enabled to perceive existing complexities within business processes and to minimize them in order to achieve a more efficient service provision. Time, costs and quality of service performance can be measured by performance measures. By best practices relating to any process element service providers are enabled to improve their processes on the basis of standard methods, established methods or examples from other companies' experiences.

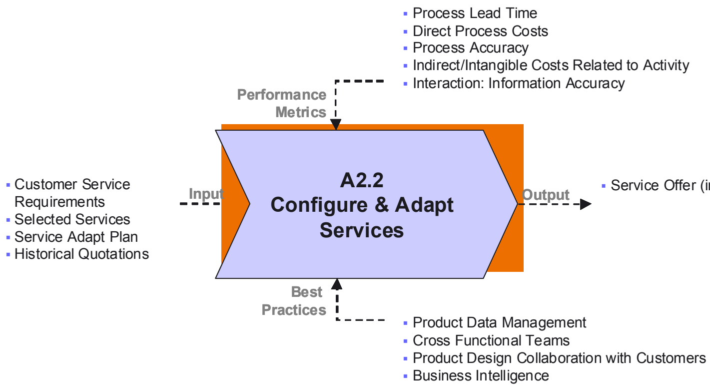

Fig. 11.3: Example of a level three process element

5 Discussion

In view of increasing importance of technical services for manufacturing companies the reference model as presented in this paper makes a contribution to closing of the existing "modeling gap" in existing company models regarding the integration of these services into current production processes. A model-based design of technical services focusing planning, initiation and realization of technical services should be supported by development of this model. Development of the model primarily focuses at a synchronous structure of production and an implementation of technical services at the interface to production synchronized with production. Furthermore the model provides applications for reorganizing existing structures as well as applications for choosing appropriate IT-solutions for technical services. Therewith companies should be enabled to determine requirements concerning process design and choose appropriate IT-solutions accordingly.

The result is divided into three different parts: tasks required for planning of services, implementation of services and processing of orders. These three parts create the reference framework which is basis for the model. Within these three parts of the model the detailed documentation of the model is conducted. Task view is divided into three levels and is illustrated in form of a function tree. Formal review of the developed model is conducted on the basis of rules of orderly modeling.

Practical applicability of the developed reference model has been shown within a company specific definition of requirements for process design and IT-support and has been demonstrated within different case studies.

6 Conclusion

By the reference model for planning and implementation of technical services as presented in this paper a tool for the model-based design and realization of technical services is given. The reference model can be immediately applied to its primary purpose. This includes planning and design of tasks and processes required for the processing of orders of technical services. Experiences with similar reference models show that a further development of the reference model is to be expected due to recent theoretical findings and practical experiences. This effect could also be considered relating to the presented reference model. From reference models for processing of orders within maintenance and service a broad model for technical services has been developed that illustrates different phases including structure, integration and implementation of processes of technical services.

By use of the reference model for definition of requirements to functions of IT-systems a basis for a systematic and differentiated examination with design of functions is given. These functions shall provide IT-solutions for structure, integration and implementation of processes of technical services. Thereby a movement of the market offer towards a higher performance level of integrated systems is to be expected. Examples for such an increase of performance level could be observed within planning and steering the production as well as planning and steering the maintenance in the last few years.

Within the design of IT-solutions for technical services the reference model can be seen as benchmark and basis for the definition of requirements to systems by using new technologies. These technologies include tele services as well as application of auto-id-technologies like RFID. Within organizational design a further development of the reference model is suggested, for example as tool for model-based benchmarking as well as for the development of performance management systems.

First experiences in application of the reference model suggest the assumption that framework as well as functional view and data view can be easily transferred to other branches.

In view of the “modeling gaps” in existing company models that could be closed by the reference model development of coordination mechanisms for an unobstructed synchronization of technical services with manufacturing should be promoted and included in the model framework in form of a separate steering view. Due to the increasing networking between companies a model-based definition of new cooperation concepts in company connections and networks is possible.

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12 Service Modelling and Engineering in the Telematics Industry – The View from the Perspective of a Toll Service Provider

Johannes Springer, Karl-Gerhard Freyer

1 Introduction

Tolling systems came up in the '70s to deal with traffic gridlocks that occurred in more and more major cities throughout the world. In the beginning, these road charging schemes were operated manually with toll booths. In 1986 the first electronic toll collection (ETC) system was introduced in Norway. From this moment on ETC systems have developed all over the world. Dedicated Short Range Communication (DSRC) systems dominated the market until 2005. An in-car transponder communicates with roadside equipment in a DSRC-based tolling system.

In 2005 Toll Collect launched the first satellite-based tolling system, requiring a minimum of roadside equipment and achieved thereby a new level of road charging flexibility. A new tolling service was designed that performs as accurately as competing services based on DSRC technology.

Designing and engineering new services until their successful rollout require a methodical approach. There exist several methods which can be applied in the context of service engineering (LUCZAK et al. 2004). When Toll Collect developed the system and the Global Navigation Satellite System (GNSS) based tolling service, the approach was mainly driven by process modeling. Changes and developments of the running system have been carried out continuously following methods like Service- Failure Mode and Effects Analysis (FMEA) during the last four years of operation (MÜLLER & TIETJEN 2003). In the future it will be a challenge for Toll Collect to modularize the existing service and to define the right level of added value to be carried out in-house (BURR 2002). These questions are the main motivation for this paper.

The objectives of this paper are:

- To describe the GNSS-based tolling service
- To make clear that not all modules of the service are toll specific

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- To argue which modules promise added value for co-usage
- To give examples how added value could be created.

If the tolling service is modularized and opened intelligently for 3rd parties, a satellite-based ETC system can provide a basis for intelligent traffic management and additional services, which will be discussed further in this document.

2 Satellite Based Tolling Service – Mass Data Processing with Unique Characteristics

The GNSS tolling service is comparable with other mass data processes. Its uniqueness is caused by the fact that it has to be operated meeting exceeding high service quality requirements. The service's accuracy and availability have to be guaranteed continuously in order to assure the toll income. For example in the Toll Collect system 3.47 billion EURO have been collected by GNSS technology in 2008.

Basically two variants of GNSS based tolling architectures can be distinguished, which show differences with regard to the division of tasks between the in-vehicle equipment (the client) also called the On Board Unit (OBU) and the central system. A *thin-client* in the vehicle performs only a few tasks of the tolling process and a larger part is carried out centrally; the situation is vice versa regarding the *thick-client* (also known as intelligent client).

The basic requirement of each OBU regardless the applied solution is to capture satellite data and calculate a position, which is the starting point of the GNSS-tolling process (Fig. 12.1). The minimum requirement on the connected central system is to allocate the accumulated road charges to the appropriate user account, which indicates the end of the tolling process. The process steps in between can be either conducted in the client or in the data centre.

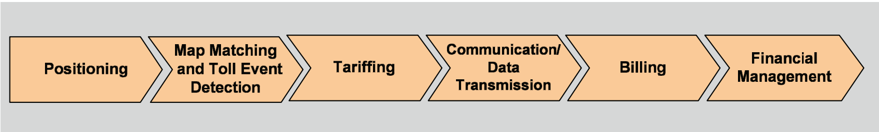

Fig. 12.1: Tolling service in GNSS-based systems

In the German tolling system whose architecture is based on a thick- client, the business process proceeds as follows:

(1) Determination of the vehicle's actual position based on satellite signals
(2) Reference the position on a map and detect a toll event ("Is the actual section a toll road/toll area or not?")
(3) Calculate the corresponding road charges according to the tariff model and create a transaction
(4) Transmit the transaction records to a central system

(5) Accumulate the transactions to a billing record and accumulate the billing records to a bill
(6) Handle the payment and clearing processes.

The tolling service as described above seems to be quite simple. It unites features from different already well known and established service fields. Every GPS navigation system is able to execute positioning and map matching, in the meantime even on mobile phones. Mobile communication and data transmission is since the massive break through of cell phone communication an important and omnipresent part of modern life. The telecommunication sector again shows that billing and financial management of the payment processes for numerous customers can be operated reliably and efficiently. So, what makes electronic tolling unique?

The ETC client autonomously calculates and transmits either position data (in the minimum), toll events or charge data records (in the maximum). Charge data records represent the amount of money that has to be billed from the customer. This means, that data representing "real money" is reported by the client – an inaccurate or lost charge data record means losing toll income at the same time. The consequences are demanding requirements concerning accuracy of positioning and availability of communication that have to be met, which are more comparable to safety of life applications than to the existing navigation or telecommunication services. For example Toll Collect has to guarantee a service level of at least 99.0% for the end-to-end functionality of the business process in all operated vehicles. In other words: At least 99.0% of the transactions which should have been produced in all vehicles at every tolled road segment must be transmitted and billed to the customer. On the other hand a 0% tolerance exists for invalid transactions: A vehicle which is not driving on a tolled road must not be tolled.

3 Description of Service Modules

Dividing products and software in to re-useable and replaceable parts and components is a common design procedure in the manufacturing industry and in the field of software engineering. In this chapter the concept of modularity will be applied in the field of telematic services. The GNSS based tolling service will be analysed with respect to two design principles (WEISBECKER et al. 2004):

- Design to Component: Existing services are divided in components that might be re-used
- Design from Component: A service is engineered using existing components.

The modules of the GNSS tolling service are decomposed in elements. It is discussed if shared usage of those modules or their elements by and from third party services is possible. This means that on the one hand there might exist the possibility that third parties use a component of the tolling service or on the other hand that the tolling service itself integrates components that have originally been assigned to third party services (“outsourcing”).

3.1 Positioning

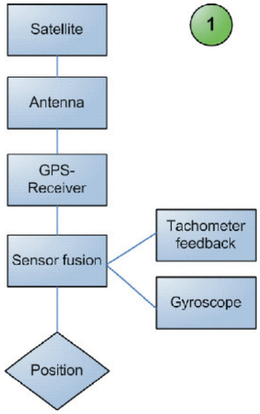

Fig. 12.2: Positioning

A GPS positioning signal is received by the OBU’s antenna and GPS receiver. Due to high requirements with regard to quality and accuracy the signal is augmented with tachometer and gyroscope information. Based on all three sources of information the final position can be determined (Fig. 12.2).

Added value for 3rd parties?
Third party services could be designed to use the OBU’s positioning signal. To use a high-quality GPS information augmented by additional sensors and the fact that no parallel positioning infrastructure has to be installed or maintained, reduces costs and creates added value for the third parties. For example the costly installation of dedicated GPS infrastructure could be avoided for an emergency-call service and furthermore the accurate position of the OBU could help to guide the emergency units.

Outsourcing possible?
It would be possible that the tolling service does not determine the position using its own dedicated infrastructure. “Positioning” could be carried out by another service (e.g. the vehicle’s navigation system) and the tolling service makes use of it. The prerequisite is that the third party device can provide position information that meets the quality levels required for tolling.

3.2 Map Matching and Toll Event Detection

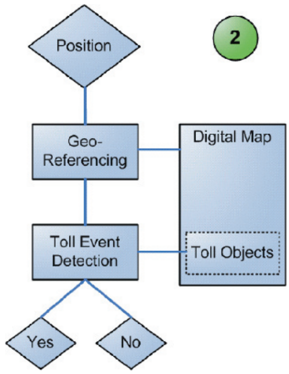

Fig. 12.3: Map Matching and Toll Event Detection

Figure 12.3 shows that the calculated position is geo-referenced on a digital map which contains the tolled road network divided in road sections (toll objects). It is checked whether the position is located on a tolled section (Toll Event Detection). This step can be done either in the OBU (thick client) or centrally if the position has been transmitted before (thin client). Due to the fact that a road network is subject of permanent changes (construction works, new roads, and new junctions) its actual situation has to be reflected continuously. In a thin-client solution the central database must be kept up to date. Whereas in a thick-client solution the OBU's digital map has to be up-dated regularly over the air. The OBU receives up to 8 updates over the air in the German system per year.

Added value for 3rd parties?
The tolling map could be co-used by third party services which would benefit from up-to-date information and short refresh periods. For example a navigation service in the vehicle could use the tolling map if a thick client solution is applied or a navigation service that is processed centrally could access the map in case of a thin client architecture.

Outsourcing possible?
Basically it is possible that a third party service offers a map which is adequate for the tolling service. If this map includes the tolled road network and is updated according to the tolling service level requirements it could be used for the tolling service as well.

3.3 Tariffing

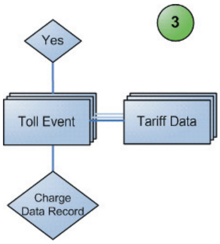

Fig. 12.4: Tariffing

If a toll event has been detected, the corresponding toll amount is determined. Tariff parameters that are considered in the German toll system are vehicle's emission class, its total weight and the number of axles. The amount and the toll event are written in a charge data record (CDR) continuously (Fig. 12.4). This step can be done either in the OBU (thick client) or centrally (thin client).

Added value for 3rd parties?
This module of the tolling service has a high specificity and offers only little possibilities for co-usage by third parties. Nevertheless the information on tariff data might be used by a routing service (e.g. navigation system) that determines the most cost-effective route.

Outsourcing possible?
Tariffing is a simple but significant part of the tolling service as road charges in terms of real money are generated. Giving away this part to third parties would mean to lose at least parts of control over this important step.

3.4 Communication/Data Transmission

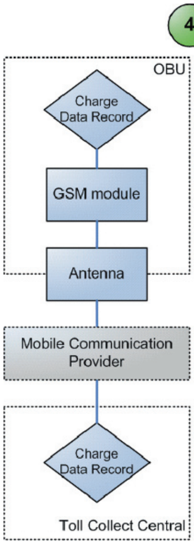

Fig. 12.5: Communication/Data Transmission

Dependent on the chosen tolling architecture (Thin/Thick) the transactions which have to be transmitted to the data centre might be position, toll event or charge data. The transmission takes place under specified conditions (e.g. CDR's value exceeds a defined amount, vehicle approaches the national border – when a vehicle approaches the national border its OBU sends the remaining CDR to the data central to avoid roaming costs for mobile communication abroad). It is carried out by a GSM module and antenna and uses the infrastructure of a mobile communication provider. Transaction safety and secured communication using advanced encryption methods are significant requirements in this step. Transmitted data is processed further on in the data centre (Fig. 12.5).

Added value for 3rd parties?
Third party services could use the OBU's GSM module and antenna to transmit data in a highly secured manner. The tolling system would act like a communication channel with an exceeding high level of transaction safety and security. Input information is transported unread and unprocessed through the system. Dedicated communication infrastructure for each third party service would become dispensable. Cost savings for hardware, installation and maintenance would be the result.

Outsourcing possible?
It is also possible that the tolling service uses communication infrastructure that is originally brought in to the vehicle for other purposes. For example in-vehicle

infrastructures like fixed in-car phones or portable equipment (PDA, cell phones linked via Bluetooth) could be used as communication devices. Again it has to be guaranteed that this third party infrastructure meets the service level requirements (SLR) concerning accuracy, availability and security that are necessary for tolling.

3.5 Billing

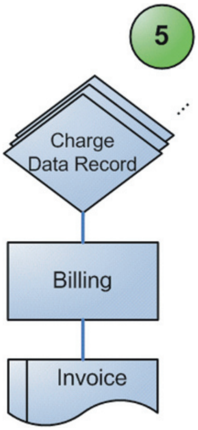

Fig. 12.6: Billing

The billing component accumulates the received CDRs on an invoice. The invoice is generated and sent to the user (Fig. 12.6).

Added value for 3rd parties?
It is possible that a toll service provider offers additional services besides tolling itself. In this case the complete portfolio of own services would be billed using one component and process. Billing of third party services in addition to the tolling service would be possible but hardly beneficial.

Outsourcing possible?
Billing is a part of the tolling service which is not very toll specific. A billing service provider, who receives the CDRs could create and send the invoices based on current mass data processes to the users.

3.6 Financial Management

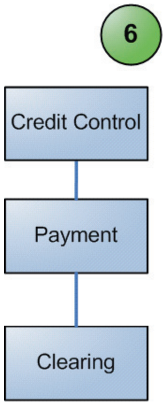

Fig. 12.7: Financial Management

This service module is concerned with the monitoring of proper toll payments and the execution of a supporting credit control system. The tolled amount has to be cleared to the appropriate recipients correctly (Fig. 12.7). There might be more than one recipient of the charges if the tolled road network consists of public and private infrastructure (e.g. concessionaires or private operators of roads, tunnels, bridges) or the toll operator offers its service in different countries.

Added value for 3rd parties?
A co-usage of the financial management module within the tolling service by third parties is not beneficial. Legislative and contractual issues affect the process and would limit the flexibility for the providers of third party services. For example road charges can be classified as a fee, a duty or a tax depending on the legislative situation in different countries or regions which results in different clearing procedures.

Outsourcing possible?
This module is the completion of the tolling service and has to manage the correct transfer of the money to the recipients. To give away the responsibility and control over this module is not an option for a toll service provider.

4 Service Engineering

4.1 Tolling as a Platform for Services

The penetration rate of tolling equipment in the toll obligatory vehicles is high, as it comes obligatory by law. Should additional services use the infrastructure or modules of the tolling service as a platform, they could benefit from high operational requirements and reduced costs for hardware, installation and maintenance (SPRINGER 2009).

Third party services can be designed and engineered on a very lean basis. They obtain needed functions by accessing and integrating the modules of the existing tolling service. So it might become possible that e.g. a navigation service has neither an own CD with the road map nor a dedicated antenna and receiver. The following process module chain (Fig. 12.8) explains the example (HERMANN & KLEIN 2004).

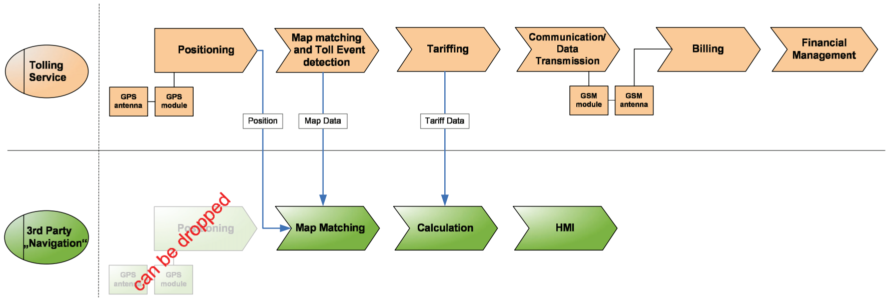

Fig. 12.8: Tolling service supplies functional modules to a navigation service

4.2 Third Party Service Platforms for Tolling

The analysis in Chap. 3 shows that some modules of the tolling service could be "outsourced" to third party services. Modern vehicles have already platforms installed that contain functionalities like positioning and mobile communication. In future it might even become possible to operate the tolling service on nomadic devices (e.g. a cell phone which is equipped with GPS-function). The platform owner or operator benefit in both cases from the compensation of costs. The occurring costs are shared between all services running on the platform or device (SPRINGER 2009).

The following process module chain (Fig. 12.9) shows how the tolling service uses functions of a tracing application. Both services run in parallel on the same hardware device.

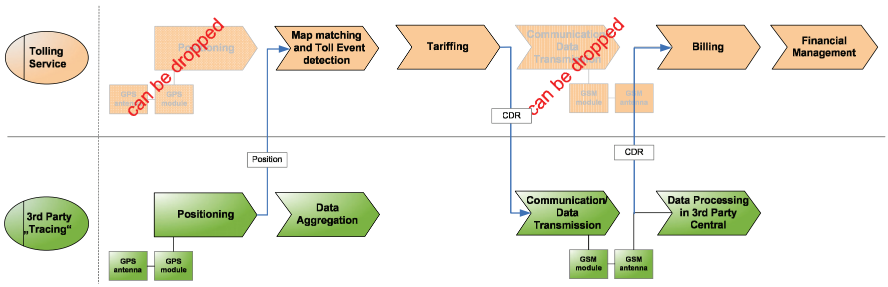

Fig. 12.9: Tolling service obtains functional modules from a tracing service

4.3 Service Level Requirements and Liability

The introduced concept proposes to join single service parts provided by different partners together and build a complete telematic service out of it. Here it is important to consider that the internal composition of the service is irrelevant for its user in the end. He expects to sign one contract with a single provider and gets the service according to the agreed level of quality. To meet the user's requirements it is crucial to organise a service level management between all involved partners that constitutes distinctive responsibilities and liabilities.

Two examples illustrate the significance of an efficient service level management in case a telematic service is provided by different partners with shared responsibilities:

(1) Tolling service: Who is responsible and liable if payment transactions are produced incorrectly and toll revenue is missing? (e.g. a total toll income of ~5 billion EURO is predicted in Germany for 2009)

(2) Emergency call: Who is responsible and liable if incorrect position data is transmitted after an accident and emergency units are not able to find the correct location in time?

To avoid ambiguities it is important that both technical and qualitative compliance levels are agreed and continuously monitored (DITTRICH & BRAUN 2004). Therefore advanced monitoring and proper diagnostic methods have to be applied in order to identify responsibilities and prove liabilities clearly. The realisation of such a harmonised service level management between different telematic service providers is a great challenge as today their requirements are only adapted to their own services and cover a broad spectrum.

5 Conclusion

The vehicle telematics market evolves slowly and is dominated by numerous single solutions that exist in parallel. Until now no application has been able to reach high market penetration and initiate the long predicted boost in the telematics sector.

For the future this can be achieved by bundling individual efforts in order to create technology standards and compatible sets of services. A wise preparation would be if all stakeholders in the field of telematics concern themselves with their own applications and respective levels of added value. Analysing and decomposing the services in their modules and elements is an applicable way for the engineering process.

The objective of the analysis must be the definition of functional requirements of the service components. Each stakeholder needs to understand which components should be generated in-house because they contain core business know-how or are not available in the market with the needed characteristics. Furthermore the analysis leads to a deeper understanding of the quality levels that can be guaranteed by its own service components. Based on this it can be estimated whether there might be a 3rd party purchaser who has an interest in integrating the component into its own services.

After decomposing services the designing and development of multi service platforms has to be done. Services operated by different providers run on those platforms in parallel and access each others components or modules.

Definition and management of service levels will become a challenge in a system where service provision is distributed among different partners. The special characteristics and parameters that are guaranteed according to a defined service level have to be known for each service module or element. Each service needs an advanced diagnosis function in order to trace the responsibility of malfunctions caused by 3rd parties. The appropriate service level management has to be so firm and transparent that liability and claims can clearly be identified and proven.

A tolling service is an appropriate application which can serve on the one hand as a platform for additional services. It comes obligatory by law and reaches thereby a high market penetration. On the other hand it has to be possible to uncouple the tolling service from a dedicated platform and integrate it on existing ones. Recent developments show that more and more services from different fields are combined on portable devices. The service of GNSS based tolling will follow this trend without doubt.

Providing the existing tolling service as a platform for additional services on the one hand and becoming independent from a proprietary hardware platform on the other, have to be pursued in parallel. Toll Collect engineers the tolling service in order to achieve both objectives without contradiction.

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13 MedicoErgonomics – A Human Factors Engineering Approach for the Healthcare Sector

Wolfgang Friesdorf, Ingo Marsolek

1 Introduction

All over the world three major challenges characterize medical work systems in the healthcare sector (MARSOLEK & FRIESDORF 2006):

An Increasing Cost Pressure

Health care expenditures have risen considerably in the past – especially in Germany they have already exceeded 10% of the entire gross domestic product (OECD 2006). The main reason for this development is a dramatic demographic change process. Enormous medical progress and continuous technological improvements, together with a positive socio-economical situation, are leading to an aging population, which is directly resulting in a growing number of elderly and chronically ill patients. The consequence is a clear tendency to longer hospitalizations and growing costs per treated case.

However, our societies are not able to allow this "cost explosion" to continue. Instead, a growing number of governmental attempts are explicitly focusing on a more efficient utilization of the existing healthcare resources. For example, in Germany hospitals were traditionally reimbursed by negotiated budgets and fees-per-day, encouraging a systematic prolongation of hospitalizations. Therefore, in 1996 this capitation system was shifted towards pre-defined case and procedure fees. Since the beginning of 2004 it is entirely being transferred into a system relying on a hospital reimbursement based on Diagnosis Related Groups (DRGs) only (HENKE & SCHREYÖGG 2004). Its aim is to reimburse the entire in-hospital patient treatment through a fixed fee depending solely on the severity of the patient's disease. As a direct result healthcare providers are today much more motivated to utilize their resources as efficiently as possible and the former

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state-regulated healthcare sector is constantly transformed into a competitive market.

Steadily Rising Quality and Patient Demands

The main causes responsible for the steadily rising quality and patient demands of the recent past are not only continuously growing health care costs, but also an increasing number of critical media reports about medical mistakes and malpractices. In particular, the publication of the Institute of Medicine estimated that in the US more people die every year from medical errors than from motor vehicle accidents (KOHN et al. 2000) and this sparked enormous interest all over the world resulting in a variety of similar studies and a vivid discussion about medical safety.

However, already in the late 1990s a paradigm change within the understanding of quality began to intrude the healthcare sector, which already revolutionized the industry and the service sector several years ago. In its center a continuous quality improvement is replacing the traditional quality control based on a systematic staff qualification as well as staff participation (see also VORLEY & TICKLE 2001, HANNEN et al. 1996, etc.). Since a couple of years ago this paradigm change within the understanding of quality is also used in the healthcare sector for a systematic reduction of medical errors. Nevertheless the vast majority of those quality management approaches still remains strictly limited to singular medical work systems instead of improving complete patient treatment chains outstretching over more than one medical institution (e.g. the out-patient physician, the hospital, the rehabilitation centre, the nursing service, etc.).

A Growing System Complexity

The dynamics of the patient treatment itself combined with the individuality of each patient and unavoidable ethical problems make the healthcare sector a complex system. Furthermore, its complexity increases continuously through the steady growth of medical knowledge and technological possibilities as well as the demographic changes described above. In this context three different attempts can be observed today for dealing with this complexity in medical work systems: (1) A professional staff specialization (e.g. to heart-surgeons, neuro-surgeons, anaesthesiologists, operating room nursing staff, anaesthesiological nursing staff, radiologists, etc.), (2) A systematic task/diagnosis oriented patient treatment for specific diseases (defining "*what* has to be done with the patient from the medical point of view") and (3) A task/diagnosis oriented standardization of the corresponding patient treatment process (specifying "*how* it has to be done" – e.g. through the definition of standardized "Clinical Pathways", "Standard Operating Procedures", etc.).

On the contrary, the professional staff specialization particularly has led to an extreme fragmentation of the entire patient treatment process and a variety of process intersections (e.g. between the emergency room (ER) and operating room (OR), between the operating room (OR) and the intensive care unit (ICU), between the intensive care unit (ICU) and the radiology department, between the intensive care unit (ICU) and the normal ward, between the normal ward and homecare, between homecare and the rehabilitation centre, etc.), each of those process intersections being extremely vulnerable for a loss of information. Furthermore, most medical specialties are served with technological solutions developed by highly specialized biomedical companies. As a result today's medical workplaces still represent a rather chaotic conglomeration of singular treatment devices than a system ergonomic workplace design characteristic for other high risk and high dependency environments like aviation industry, nuclear power plants, etc. (MARSOLEK & FRIESDORF 2006).

2 Problem

The challenges described above clearly show the obvious necessity for a sustainable re-engineering of the historically grown healthcare sector – not only for the development of patient-centred treatment processes, but also for the design of user-oriented medical workplaces. Especially the introduction of more and more performance based health care financing systems and the growing competition among healthcare providers are setting clear signals from the outside for a more efficient utilization of resources, while neither a decrease in treatment quality and patient safety nor staff health and motivation can be risked. If this optimization process can not be achieved, only two scenarios are imaginable: Either inefficient medical work systems will go bankrupt on a micro-economic level or our society will become unable to further finance the required medical and technological progress necessary for keeping a leading position in today's international health care market on a macro-economic level.

But although the necessity for such a systematic re-engineering approach is obvious, the establishment of a successful change process from the inside is often hindered through the historically grown structure and complexity of the healthcare sector itself. As a direct consequence besides the traditional question about "*what* has to be done with the patient from the medical point of view?" the organizational question "*how* can we achieve this as efficient and safe as possible?" as well as the ergonomic question "*how* do we have to design adequate user-oriented medical workplaces?" have to gain more and more importance. But while our scientific community already has an extremely high competence for answering the first question, research approaches for answering the two other ones circumscribing the newly developing research field of "MedicoErgonomics" have just started (see also DONCHIN 2007).

3 Objective

Following the core definition of "Ergonomics" (IEA 2000) the sub-discipline of "MedicoErgonomics" is the scientific discipline concerned with the understanding of the interactions among human and other elements of medical work systems, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being (of patients as well as staff and family members) and overall system performance. MedicoErgonomists contribute to the design and evaluation of tasks, jobs, products, environments and systems in order to make them compatible with the needs, abilities and limitations of people (patients as well as staff and family members) (FRIESDORF & MARSOLEK 2008).

Thus, the general aim of MedicoErgonomics is exactly the same as the overall goal of human factors engineering and ergonomics as defined by LUCZAK (1998): the systematic rationalization as well as humanization of work systems and work processes.

4 Basic MedicoErgonomic Models for the Healthcare Sector

For this newly developing research field of MedicoErgonomics (see also DONCHIN 2007 as well as FRIESDORF & MARSOLEK 2008) we have developed the following five models especially suited to deal with the given complexity of the direct patient treatment processes in the healthcare sector.

4.1 The Extended Patient-Staff-Machine-Interaction-Model

In industrial work systems human factors engineering and ergonomics is using the classical "Human-Machine Interaction Model" (see also LUCZAK 1998 and BUBB & SCHMIDTKE 1993) to understand the interaction between humans and machines on a micro-ergonomic level with a given task objective to produce, maintain or repair a product. But in the healthcare sector it is the patient who is the "work object" playing a double role. For a successful treatment the patient (Latin: patiens = suffering) can not only be interpreted as a passive "work object" (e.g. the anesthetized patient during surgery, etc.), but in most cases (except for specific paediatric, geriatric or psychiatric cases) has to be integrated as an active "co-worker" into the treatment decisions and processes (e.g. deciding about the surgical intervention, cooperating during physiotherapy, etc.). An extended "Patient-Staff-Machine-Interaction-Model" (as shown in Fig. 13.1) is needed to emphasize the patients' important role in the healthcare sector.

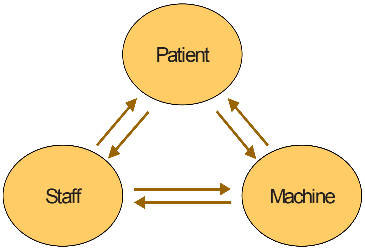

Fig. 13.1: The Extended Patient-Staff-Machine-Interaction-Model

Using this model three different kind of possible interactions have to be considered (FRIESDORF 1990, FRIESDORF et al. 1993, FRIESDORF et al. 2007): (1) Between staff and machine – similar to those in industrial work systems. (2) Between patient and machine (medical devices) including patient monitoring (e.g. measurement of physiologic variables such as ECG, blood pressure, etc.) and patient therapy (e.g. pump driven drug applications, artificial ventilation, etc.). (3) Between staff and patient including verbal communication, interpersonal diagnostics (e.g. feeling the pulse, seeing an inflammation, smelling an infection, etc.) and therapy (e.g. moving a joint by physiotherapy, etc.). Also within the three different categories of elements interactions can take place: between different staff members, between different devices and between the patient's organs.

4.2 The Adapted Medical-Task-Model

With the patient, staff and machines being the core elements of the "Patient-Staff-Machine-Interaction-Model" (as shown in Fig. 13.1), all interactions between those elements represent the work processes necessary to complete a given task objective as described within the general ergonomic work process model of BUBB & SCHMIDTKE (1993).

However, for medical work systems the task objective is defined by the staff itself according to the patient's initial status and the anticipated patient's final status (outcome) after the task completion (as shown in Fig. 13.2). As a matter of course, the task completion does not always have to be combined with the curing of an illness (e.g. palliative treatment of a patient with inoperable cancer) (CARAYON & FRIESDORF 2006).

Reaching a high "quality" is then achieved if the task completion is corresponding to the given task objective. Therefore, a high quality can only be achieved by defining the correct task objective and deciding upon taking adequate diagnostic and therapeutic measurements ("*what* has to be done with the patient from the medical point of view?"). In addition to that the "efficiency" takes also the used resources into account (e.g. needed staff, used machines, required material, etc.).

As soon as the question "*what* has to be done with the patient from the medical point of view?" is correctly identified and clearly defined, a high quality and efficiency can only be achieved by a process organization ("HOW it has to be done?") being free of process deficits. Therefore, all process deficits have to be eliminated systematically for a safe and efficient patient treatment.

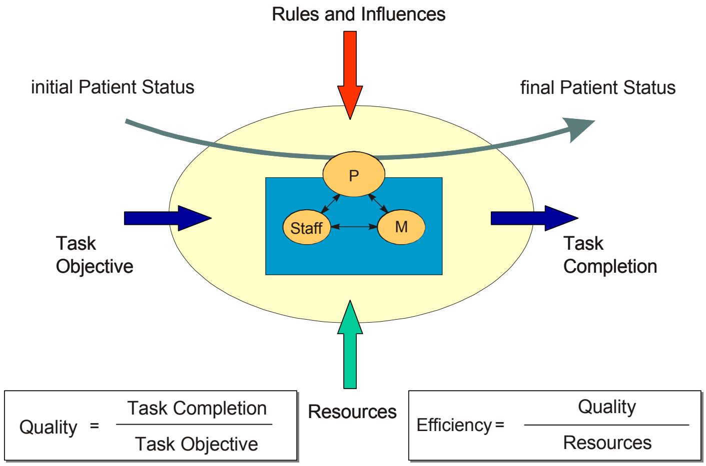

Fig. 13.2: The Adapted Medical-Task-Model (P = Patient and M = Machine)

Work processes in industry are decomposed hierarchically down to a level at which the task objective can be defined and all work actions can be controlled by a single responsible worker or team. Thus for example the production line of a car can be anticipatorily designed in detail. In the healthcare sector a similar approach always has to take the individuality, uncertainty and dynamics of the patient treatment processes into account. The complexity of medical work systems hinders a complete anticipation of all possible actions. Instead medical work systems require a strategic treatment planning (FRIESDORF et al. 2007).

4.3 The Recursive Hierarchical Task-Process-Task-Model

Having a particular diagnosis, the entire patient treatment process can also be decomposed at a high system level into a sequence of subtasks (processes) according to clinical pathways (e.g. patient admission, diagnostics, patient preparation for surgery, execution of the surgical intervention, post-operative patient recovery, patient discharge, etc.). Figure 13.3 shows the recursive hierarchical Task-Process-Task-Model enabling such a heuristic decomposition of complex tasks (CARAYON & FRIESDORF 2006, FRIESDORF et al. 2007).

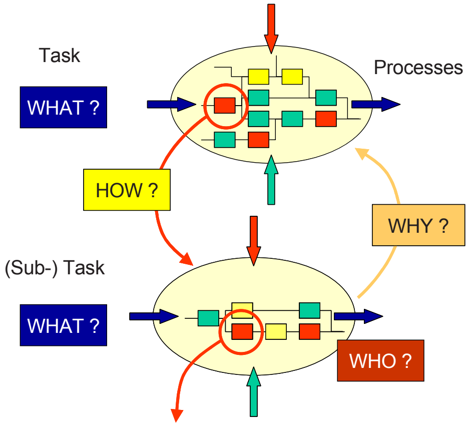

Fig. 13.3: The Recursive Hierarchical Task-Process-Task-Model

A task objective is completed by sub-tasks. The ergonomic questions "*how* is it done?" and "*how* it has to be done?" can therefore be answered by a systematic process analysis and optimization. All critical sub-tasks should always be analyzed on a more detailed level looking for potential process deficits. This can be done recursively until the work processes consist of elementary activities (e.g. adjusting an infusion pump, confirming an alarm). The "*why* is it done?" question validates tasks, supports the re-composition of tasks, and leads to re-defining entire treatment sequences on a higher system level. The process quality and efficiency can be assessed at each system level according to Fig. 13.2. The question "*who* is responsible?" helps to clarify whom's responsibility it is, to guarantee a high process quality and efficiency in the given (sub-)system.

A similar decomposition of complex tasks is discussed by researchers examining human decision making. RASMUSSEN et al. (1987) describes a mental model based on five different levels for task sub-routines, in which the "*how*?" question also leads to a more detailed level, while the "*why*?" question leads to a higher system level and the "*what*?" question describes the task/sub-task at the momentarily focused system level.

4.4 The Strategic-Treatment-Management-Model

MALIK (1995) has defined a general strategic management concept for work systems to cope with complexity by using three different management levels: the normative, strategic and operational level.

In analogy a strategic patient management can be defined for the healthcare sector (FRIESDORF et al. 1994, 2007). Combined with the recursive hierarchical Task-Process-Task-Model (shown in Fig. 13.3) the whole patient treatment can be interpreted as a fractal navigation system. Each sub-system has its own strategic management to deal with a given uncertainty (as shown in Fig. 13.4). The task/sub-task completion is planned to be performed by specific procedures (sub-tasks scheduled on a time axis) based on superior management strategies.

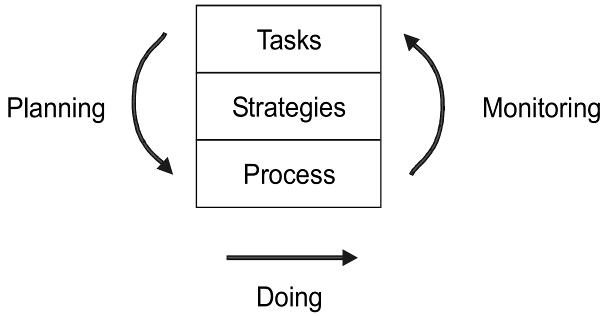

Fig. 13.4: The Strategic-Treatment-Management-Model

4.5 The Process-Standardization- & Navigation-Model

With the help of the recursive hierarchical Task-Process-Task-Model different levels of work processes can also be identified within the entire patient treatment process based on their degree of granularity. The macro-level represents the entire patient treatment chain (e.g. the in-hospital treatment and out-hospital rehabilitation for a total hip-joint replacement, for a tumour removal, etc.). On the meso-level different treatment modules (e.g. the anaesthesia induction, the surgical intervention, etc.) can be identified. Furthermore, those treatment modules can be differentiated into single procedures on a micro-level (e.g. the pre-operative information collection using the patient record, the patient's pre-medication, etc.). Between these three system levels additional levels can be defined according to given requirements. (FRIESDORF et al. 2007)

Using this system ergonomics approach for a systematic classification of medical work processes we have to differentiate between "Process Standardization" and "Process Navigation" since a classical "Treatment Standardization" is only possible for elective interventions using "Standard Treatment Modules" and "Standard Operating Procedures". The complexity of acute patient treatment processes requires an individual "Process Navigation" by combining "Standard Treatment Modules" with "Navigated Treatment Modules" and "Standard Operating Procedures" with "Non-Standard Operating Procedures" as shown in Fig. 13.5.

Following the other direction within this systems approach it is the interlaying meso-level, which is integrating different medical procedures to superior treatment modules. While helping to specify the context and interrelations, they are giving up process details (e.g. guaranteeing the oxygenation, stabilizing the blood pressure etc.). The "*HOW?*" question ("*How* is the blood pressure stabilized?")

always leads to a more detailed analysis level. In the other direction the question "*WHY?*" ("*Why* is an X-ray needed?") leads to the next superior (but less detailed) level.

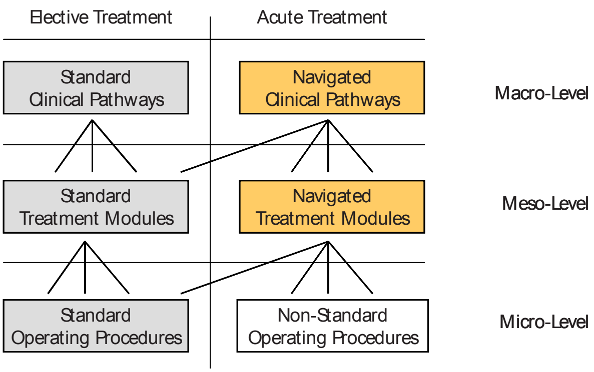

Fig. 13.5: The Process-Standardization- & Navigation-Model

In this context "Clinical or Critical Pathways" represent the ergonomic macro-level and "Standard Operating Procedures" the ergonomic micro-level (KOX & SPIES 2005). But on each ergonomic analysis level the following "standardized" and "non-standardized" process modules have to be differentiated based on the degree of complexity, which is characteristic for standard (elective) and acute (emergency) patient treatments (FRIESDORF et al. 2005):

"Standard Operating Procedures (SOPs)" can be identified within the most detailed system level (micro-level) as work tasks that are not suitable for further subdivision from the clinical point of view. However, the "*how*?" question might still lead to a sub-process needed for an ergonomic optimization. The SOP "intra-muscular drug application" may serve as an example. A more detailed analysis (using the "*how*?" question) leads to the sequence: fetch drug, syringe, needle etc., open drug ampoule, fill syringe, etc. This level is important for a systematic risk analysis (e.g. taking a wrong drug, etc.) and an ergonomic optimization but does not lead to "complete" clinical tasks (meaningful for a patient's treatment).

Superior "Standard Treatment Modules" can be compiled of several SOPs within the meso-level. (e.g. the anaesthesia induction). Their standardization results in "Standard Treatment Modules". The "*how*?" question leads to sub-tasks and therefore directly or recursively to the according SOPs.

"Standard Clinical Pathways" represent the planning of complete treatment chains (e.g. a hip replacement) on the macro-level with the help of standardized treatment protocols defining which treatment modules have to be performed in which sequence.

For acute (emergency) patient treatments "Navigated Clinical Pathways" and "Navigated Treatment Modules" are needed since the complexity of acute (emergency) patient treatments limits a complete treatment anticipation. The required decisions for optimal patient treatments often have a strategic character taking the given (incomplete) information about the patient on one hand and the available resources (human, technology, procedures) on the other hand into account. Therefore the patient treatment is much more like navigating a boat in a heavy sea. As a result "Navigated Clinical Pathways" characterize the macro-level of an acute patient treatment. "Standard Treatment Modules" as well as "Navigated Treatment Modules" are compiled according to the situation. "Navigated Treatment Modules" are compiled using "Standard Operating Procedures" as well as "Non-Standard Operating Procedures". Primarily, they are needed for managing unexpected crisis situations with a high complexity.

A process monitoring based on a systematic risk analysis has to ensure, that variations from those "Standard Clinical Pathways" are detected as early as possible to immediately enable the necessary treatment individualization (e.g. when a heart attack occurs during elective surgeries). Improving patient safety and efficiency can therefore only be achieved by finding the right balance between process standardization and process navigation. The right balance is defined by the given situation (the patient's status and available resources). Neither a treatment improvisation for elective (planable) patients nor a forced and inadequate standardization of acute (unpredictable) patient treatment processes can lead to the desired medical outcome. Instead the described differentiation between elective (planable) interventions and acute (emergency) interventions has to become a first basis for a systematic and extensive development of "medical process maps" helping to support

(1) A systematic standardization of clinical pathways for elective (planable) interventions on the macro-level based on standard treatment modules from the meso-level and standard operating procedures from the micro-level as well as their continuous evaluation to achieve an evidence based medicine wherever possible;
(2) An individual and flexible treatment navigation for acute (emergency) interventions on the macro-level by combining standard and/or navigated treatment modules from the meso-level with standard and/or non-standard operating procedures from the micro-level;
(3) A consistent and comprehensive process monitoring by defining adequate process benchmarks and risk monitoring strategies for detecting critical process deviations as early as possible and immediately correcting treatment strategies throughout all elective (planable) as well as acute (emergency) interventions.

5 Conclusion

The five theoretical models described above are based on the results of numerous analysis and optimization projects in medical work systems combined with years of clinical experience.

Evaluating their practical suitability for a systematic patient safety and efficiency improvement will be the next step to take.

However, their aim is to emphasize that a sustainable improvement of patient safety and treatment efficiency can only be achieved by constantly considering

(1) The given complexity of medical work systems resulting from the patients' double role as passive "work-objects" and active "co-workers" (as shown with the help of the extended Patient-Staff-Machine-Interaction-Model);
(2) The medical work system's underlying task objective (resulting from the initial patient status and desired treatment outcome) as well as task completion plus used resources for measuring the achieved process quality and efficiency (as shown with the help of the adapted Medical-Task-Model);
(3) A heuristic decomposition (analysis and optimization) of complex work tasks answering the questions "*how* is it done?" and "*how* it has to be done?" (as shown with the recursive hierarchical Task-Process-Task-Model);
(4) A strategic patient management on a normative, strategic and operational level as a fractal navigation system (as shown with the help of the Strategic-Treatment-Management-Model);
(5) An adequate balance between process standardization for elective, planable interventions and process navigation for acute, emergency interventions (as shown with the help of the Process-Standardization- & Navigation-Model).

In addition to this, all practical project realizations will only be successful when simultaneously focusing on both major aims of human factors engineering and ergonomics alike as described by LUCZAK (1993): the systematic rationalization as well as humanization of the underlying work systems and work processes. Only then and in combination with a participatory re-design approach we will be able to achieve not only the desired continuous improvement of medical work systems, but also the urgently needed intrinsic motivation of the involved clinical staff (see also LUCZAK et al. 2006).

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14 The Impact of Ergonomics

Ernst A.P. Koningsveld

1 Introduction

Ergonomists offer services to organizations. The goal of their work is to provide safety and health at work in combination with a sound human performance. However, the impact of ergonomics efforts is not always as good as ergonomists and human factors specialists want. This chapter aims to support these specialists in their work. Starting with the developments in ergonomics from its two basis backgrounds, it focuses on the benefits of ergonomics for companies and workers. An example of an approach, performed at large scale, illustrates how the impact of ergonomics can be illustrated. The chapter continues with a view on education and training of skills and competencies, and with a note on certification.

2 Developments in Ergonomics

Ergonomics has its origin in two different approaches: one focuses at the prevention of health (occupational safety and health, OSH), the other aims to promote human performance. First the history and scope of both is described. Then we describe the actual focus on system's and company's performance, which gives a sound basis for ergonomics impact.

2.1.1 Ergonomics to Promote Safety and to Protect Health

For many years, health protection and providing a safe working environment have been important matters. The relation between occupations and injuries was documented centuries ago. Bernardino Ramazinni (1633–1714) wrote about work-related complaints in the 1713 supplement to his 1700 publication, "De Morbis Artificum" (Diseases of Workers; RAMAZZINI 1940). Less known is the work of Wojciech Jastrzebowski, who created the word ergonomics in 1857 in a

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philosophical narrative, “based upon the truths drawn from the Science of Nature” (JASTRZEBOWSKI 1857).

In the second half of the nineteenth century health impairment of the working population became an item of political interest. In the Netherlands the protection of the health of children at work was the real start, with the Dutch Legislation on Child Labor in 1874. Legislation, inspections, interventions, trainings and education followed. Though much progress has been achieved in labor protection over more than a century, even today working can be unsafe and overstraining, resulting in large numbers of early dropouts. The quality of working conditions differs over regions and over sectors. LEIGH et al. (1999) indicates that the incidence of occupational injuries and occupational diseases in developing countries are more than twice as high as in so-called Established Market Economies (Northern America, Europe) of in the Formerly Socialist Economies of Europe.

Fig. 14.1: A daily work situation in a high tech assembly industry in The Netherlands, 2001

The scientific knowledge about human's capacities has been largely extended. Limit values for actual work loads were defined and introduced at the level of legislation, of standards or as good practice agreements between employers' organizations and unions. Solutions for hazardous workloads and unsafe conditions have been developed, tested and implemented. Never the less, even today, you will not have to search long to find adverse working conditions, even in the most industrially developed parts of the world, or in high tech industries (Fig. 14.1). Shareholders and management of companies seem to misunderstand the long term benefits of safe and healthy work environments.

The consequences of poor working conditions are serious. Workers may suffer from health impairment and experience a too poor quality of life. Injuries decrease their power to earn money, and ultimately their independence in life is affected. The employer maybe confronted with high costs, though the direct financial effects differ widely over countries. In the Netherlands the employer is held responsible to pay at least 70% of wages during the first two years of sick leave (This rule counts for all causes of sick leave, either work related or not. In collective agreements the level of compensation to be paid by the employer is arranged between 70% and 100% of regular wages.). In other countries this period is far less and applies only cases of occupational accidents and injuries. Relative low financial effects for the employer may make him less motivated to prevent occupational hazards. In several countries the employer cannot only be held responsible as a legal party, but as an individual as well for cases of occupational accidents or occupational diseases.

Many other costs can occur as a result of injuries and accidents: productivity losses, quality problems, reduced motivation, or loss of unique expertises. Eventually these effects may lead to the loss of clients and affect the market position of the company.

At the level of a sector, the attractiveness of jobs may fall behind other jobs, making it hard to find new workers. For instance, physically straining work is less attractive to youngsters than being a machine operator.

At the societal level, the costs of poor working conditions are a real burden. Several European studies show that the societal costs are in the order of 2–3% of the Gross National Product (GNP) (KONINGSVELD et al. 2003, KONINGSVELD 2005). Health effects, resulting in absence of work, occupational disability and medical treatment, are responsible for up to 80% of these costs. The quoted Dutch study provides a good overview of cost categories and their values, but does not include all effects. It turned out to be difficult to validate the financial effects of poor working conditions on companies' performances. So these costs are not included; some experts estimate that these may be another 2–3% of the GNP. Others, including the International Labor Organization (FORASTIERI 1999) point at the importance of better working conditions for companies' performances. Many individual companies and organizations are cost driven; but according to OXENBURG et al. (2004) and MARLOW (2006), cost benefit considerations related to occupational health and safety are scarcely out of the egg.

There is a growing understanding that working conditions are important for the competitive strength of a country or an economic region like North America or the European Union (KONINGSVELD 2005). Lack of workforce is a thread for the western economies: a decreasing workforce has to earn the money needed to keep the elderly alive. The costs of health care are rapidly increasing. There is a drive to extend the working life to more than 40 years. People are expected to work till their 67th or even 70th. These trends emphasize the need for prevent ion of health impairing work and the creation of safe working conditions. Besides that there is a new challenge for ergonomists: do we have to revise limit values for work loads in this respect?

It is not easy to express lost healthy lifetime and individual harm in financial terms. These factors are not included in the fore mentioned studies about the costs of poor working conditions. But today, these factors are becoming important matters in the scope of politicians, employers and workers, and their representatives.

2.2 Ergonomics to Promote Human Performance

The development of ergonomics in relation to human performance has its roots in studies on physical performance. Employers were highly interested to increase human performance, and so in the maximum capacities of humans. Scientific Management, a method that improved worker efficiency by improving the job process, became popular. Frederick W. Taylor was a pioneer of this approach and evaluated jobs to determine the "One Best Way" they could be performed. At Bethlehem Steel, Taylor dramatically increased worker production and wages in a shoveling task by matching the shovel with the type of material that was being moved (ashes, coal or ore). Frank and Lillian Gilbreth made jobs more efficient and less fatiguing through time motion analysis and standardizing tools, materials and the job process. By applying this approach, the number of motions in bricklaying was reduced from 18 to 4.5 allowing bricklayers to increase their pace of laying bricks from 120 to 350 bricks per hour (ERGOWEB WEBSITE). As defence was a large employer and battle actions were highly demanding, the armed forces formed a major target group for ergonomics studies. Later, the scope changed from maximum performance to "optimal", indicating the workload that workers can endure for a lifetime of full-time working weeks. Today such studies are still important for many trades in which physical efforts are required. In addition, ergonomists investigate how to design workplaces that allow maximum performance without negative effects on physical workloads and discomfort (e.g. VAN RHIJN et al. 2005).

From the nineteen-forties, ergonomists have been involved in cognitive, mental and organizational performances. As several ergonomics publications indicate, during World War II, more planes crashed on their way to the battlefields or on the return flight, than were shot by the enemy. A vision on "human centred technology" was born, and has become important. Today, the fast development of new technologies makes this even more important.

Still a large gap exists between the designers and users of information and communication technology. Designers show too little understanding of the way humans deal with technology, or how they want or expect technology to work. As early as the nineteen-seventies, studies about control room operator's behaviour and design recommendations were published by EDWARDS and LEES (1974). The European Coal and Steel Community put much effort in this field. Later, mistakes in control room operated industries resulted in serious accidents. Analyses of these accidents usually show failures which could have been solved by good ergonomics system designs. Examples of such accidents with proven human factors' misfits are: the Three Miles Island nuclear incident (1979), the Bhopal catastrophe (1984, release of toxic compound), or the Flixborough disaster (1974, an exploding chemical plant). Reliability assessment became an important, though still underestimated item. Authors like Kirwan published several books on the matter (KIRWAN 1994), also focussing on the mental workload and the internal process representation of the human operator.

Other studies on human performances based on mental processes focus for instance drivers' tasks in cars, trains, ships, and even in bicycle riding. Recent studies warn for the hazards of dual tasking, for instance when mobile telephoning during driving.

Organizational design and management has become one of the large topics in ergonomics. Subtopics, like socio-technical design and participatory ergonomics, get much attention at ergonomics conferences and in literature. This field of interest is not completely free of hypes. Every decade new gurus or visions arise, many of which deal with human performance. SHAPIRO (1996) has written a rather critical review of work organization design and management views, entitled Fad Surfing in the Boardroom: managing in the age of instant answers. Much organizational hype passed by, such as total quality management, systems re-engineering, Six Sigma, or learning organizations. Of course, each of these has its values. But Shapiro states that, at the end, the organization's consultants are the only ones who benefit. Probably, this is because many of these approaches don't address the actual production tasks at the shop floor. And that is basically what ergonomists and human factors specialists do.

2.3 Trends in Ergonomics

Over the years, trends in society lay the emphasis one time more on health prevention, and next more on human performance. Today, we see these two lines very well coexist. If economy is low, cutback of costs is the primary focus in most of business. Some ergonomists do illustrate the costs of poor working conditions, and the financial effects of occupational injuries and accidents at work. By doing so, they create their market for preventive projects. Other ergonomists stress the positive contribution of ergonomics to human performance in an increasing international competition. In both approaches there has been a growing interest in the cost benefit aspects of ergonomics (DUL & NEUMANN 2007).

In economically good times, ergonomists may want to deal with *comfort* as a marketing concept and with the benefits of innovations in work processes, contributing to human performances in *creativity, collaboration,* or *self-development.*

Human activities are constantly changing. New trends in the information and communication technology have changed the work of many dramatically. There is an ongoing process of new trends in the organization of work. World-wide we see people migrate, resulting in a growing diversity within the workforce. There is a trend to keep aging workers at work, and to make work accessible for people with handicaps of any kind. Sports and leisure have emerged as new fields of application of ergonomics.

For ergonomists and human factors experts these trends are challenges for their contribution to "sustainable performances of humans". This statement expresses that ergonomics and human factors endeavour to create work in which humans perform well during all their working life. This means that workplaces and organizations are safe, do preserve humans' health, and allow them to develop themselves continuously. If ergonomics can achieve that, we can really speak of societal impact!

2.4 The Position of Ergonomics Within Companies

So, ergonomics really benefits human activities. Nevertheless, two questions rise:

(1) Isn't management interested in their most important and most valuable asset: the human resources?
(2) How comes that ergonomics (or Human Factors) does not reach the boardrooms?

Regarding the first question, there is a trend that shareholders stress short term financial performances, which may very well conflict with durable and sustainable human performances. Ergonomists need to be keen. Offending short-sightedness of management seems plausible, but will not work. It is better to find ways to prove the short term benefits of ergonomics. Ergonomists have adequate knowledge of the relation between humans' health and humans' performances. They can very well argue the importance of these factors for companies' health and performances, both at short and long term. According to GALLAWAY (2007) it is time to do so; don't wait until tomorrow.

DUL and NEUMANN (2007) analysed the drivers behind business strategies. Obviously, ergonomics, in and of itself, is not a strategy or business goal. They show that ergonomics is a potentially important feature of strategy formulation and implementation, since attention to ergonomics can contribute many different aspects of business performances (profit, cost minimization, productivity, quality, flexibility).

Referring to the second question, "why does ergonomics not reach the board room?" One can see that ergonomists tend to pay only little attention to trends in management topics and management styles. Ergonomists scarcely use core business parameters to promote their consults. You will find little, when you try to find in ergonomics research reports aspects like costs and benefits, quality of production, market attractiveness of product designs, lead time, or flexibility of production.

As early as 1989 a conference Marketing Ergonomics was held in The Netherlands. The focus was to get more impact with our work. In 2006 the New Zealand Ergonomics Society chose the same topic for their annual meeting. Still, the fact that most ergonomists have an academic home base, implicates that scientific justification gets more attention than implementation of results.

3 Ergonomics' Benefits in Practice

3.1 General Benefits of Ergonomics Interventions

As stated, ergonomists should focus on the benefits of their work in terms of core business values. That means that the effects on the system's performance should be analysed. To prove effectiveness is a relatively new field of interest in the profession of ergonomics. Table 14.1 shows the effects that ergonomics interventions may have and that are core business values.

Table 14.1: Potential core business effects of ergonomics interventions (KONINGSVELD 2005)

Increased productivity More efficient movements Less fatigue Better motivation Less personnel turnover Fewer temporary workers Easier to assemble products	**Lower operational costs** Fewer lost working days Fewer cases of disability Easier and quicker return to work Fewer temporary workers Lower costs to assist sick workers Fewer rejected products
Improved competitiveness Improved production / prod-uct quality Increased flexibility of production Improved workers' satisfaction Improved clients' satisfaction Higher reliability of delivery Better position on the labour market	**Company's values/standards** Health and safety taken seriously "We are proud of our workers" Improved safety: lower accident rate Sustainable production, products

Not all of these can easily be presented as objectively assessed data. That may be a problem for ergonomists, general management is used to work with a combination of quantitative and qualitative effects, and can very well base their decisions on those.

3.2 Costs and Benefits

In the ergonomics society there has been a great demand for costs and benefits analyses. Many ergonomists hoped to be more convincing if they could demonstrate the financial effects of their work. Some good case studies were done. However, for a long time the development of a generic model was considered too difficult. OXENBURG et al. (2004) did great work in the field, but the need remained for an as simple as possible approach. In 2005 four approaches were presented and discussed at a WHO and NIOSH sponsored conference (EIJKEMANS & FINGERHUT 2005). None of these was considered to be the ultimate solution for generic use. One was too time consuming, another too complicated and a third one required much competence and expertise of the analyser. Since then, TNO in The Netherlands has made much progress. The next example may illustrate this.

3.3 A Cost Benefit Model for Interventions in the Long Term Care

Based on participatory principles, which are familiar to many ergonomists, it was possible to develop a cost benefit and human productivity models that are at least generic for a certain sector. TNO in The Netherlands developed such a model for the long term health care. The model was developed as part of a large national program called "Care for better". The model has been in use since the end of 2007, and health care institutions have used the model for almost one thousand intervention cases.

The sector is confronted with an increasing demand for care, and a (slightly) diminishing workforce. The challenge for all institutions is to develop smarter work, which is specified by:

- increased labor productivity
- (preferably) reduced work loads
- at least the same level of care quality.

Interventions may be better ergonomics, organizational changes, task diversification, improved safety, and so on.

For the analysis software is provided through the Internet (ZORG VOOR BETER WEBPAGE). In this chapter examples of the tool are shown as screenshots.

The effects are measured by comparing the existing work situation with the situation after the intervention. The latter is first analysed as a virtual situation, later an effect assessment is made to evaluate the real effects.

First, it is important that the work evaluated process is exactly defined: with which activity does the work process start, and at which point is it ended? For how many patients is care supplied, and which is the time slot? Examples are:

- Washing 60 bedridden patients seven mornings per week;
- food distribution for 5 living rooms of 8 patients; the distribution starts at arrival of the electric transport cart, and ends when dishes are washed and returned in cupboards;
- detecting and bringing back wandering demented elderly, as a mean 2 times per day;
- the intake process of one client. 120 clients per year. The intake starts at the first telephone call, and ends when the decision is announced to the potential patient.

To be specific is essential to prevent mistakes in assessments.

In the analysis an important factor is labor productivity. The old situation is analysed into tasks; for each task the employee(s) performing the task are identified, including the time spent. The number of employees with that position performing the task together is noted (e.g. when manually lifting patients) (Fig. 14.2). Time spent is estimated or assessed, depending on the chosen level of accuracy.

The analysis is best made by two or three nurses and a team leader. It is remarkable that many a time this analysis already indicates that work is not performed in line with written procedures.

Fig. 14.2: Screenshot of the task analysis. The example comes from a nursing home. First task: one nurse passes on her service to another, taking as an average 2 minutes per client; this happens 3 times per day. Second task: the team leader is also present when passing on service. Third task: for each patient a nurse consults the individual medical file 3 times per day, taking 5 minutes as a mean, including walking to the central computer. Fourth task: reporting new information in the individual medical file is done as an average two times per day, taking 4 minutes per time of one nurse

To make the virtual analysis, a participatory work session is held. The project manager is suggested to invite a line manager above the level of team leader, two employees performing the task, a team leader, a client representative and a controller. Optional participants are: a HRM official, a supplier of technical equipment that is foreseen to be part of the innovation.

For not too complex interventions, the work session takes about 2 hours, and is divided into 6 steps.

Step 1

The work session starts with the case description: what is part of it and what is not. Then the zero (existing situation) assessment of tasks and time spent is presented to all. Agreement is expressed, if necessary after adaptation of data.

Step 2

The quality of care is rated for 8 quality aspects on a 1–10 scale. For each of four sub sectors specific aspects are provided. If individual ratings differ, a discussion on motives follows, resulting in most cases in a collective standpoint.

Step 3

The project manager describes the virtual situation after the intervention. In case of several options, the options are discussed. The situation is as good as possible defined. Then the tasks are discussed: which of the actual tasks remain, are these performed the same way in the same amount of time? Which of the tasks are no longer performed, and which new tasks have to be introduced? Are the same employees involved? How much time cost each of the tasks, and so on.

The data are filled in, in the virtual assessment part of the tool.

Step 4

The quality is rated by all participating for the virtual situation, according to the same procedure as in step 2.

Step 5

The costs and benefits part of the tool is filled in. Also here, the virtual situation is compared to the actual situation. The labor productivity is combined with costs per man hour per position, resulting in the labor costs “before and after”.

Investments taken into account are:

- Consultancy costs: in many cases a consultant is hired to analyse the actual situation and to help select good solutions;
- time of own staff to select interventions; not all institutions calculate time of managers in this respect, but time of nurses, who must be replaced when working for a project, results of course into costs;
- purchases. The direct expenses for hardware, software and so on;
- installation costs. Next to installation hardware, one may consider here procedures to be developed;
- initial costs, like training employees, a temporary reduced production;
- the term of amortization (1, 3, 5 or 10 years) and the interest rate applied;

- rest value: some investments may have a rest value after the term of amortization;
- grants, subsidies minus the costs to acquire those.

Operational costs that are taken up, are:

- Maintenance costs;
- energy and other consumables; think of liquids, bandages, needles, cleansing agents;
- other structural expenses; e.g. travel costs, subscription costs, training of new staff.

Changes in income as a result of the intervention are indicated. In the care most income is paid by the insurance companies. Interventions may lead to less or more compensation.

By doing so, the financial aspects are determined. Of course not all data may be available in the work session. Some homework after the session maybe required.

Where actual data are missing, the group may decide to use best guesses for certain parameters. It is wise to keep a record of hard data and estimations. When all data are ready, a so-called sensitivity analysis can help to find the factors that are critical for the outcome. If wished, these can be assessed with more accuracy.

Step 6

The internet tool helps to determine *non financial effects* of the intervention.

First effects on working conditions are scored. For the physical, the mental, and the emotional workloads the group can identify if there will be a decrease of the work load, a substantial decrease, an increase, a substantial increase or no change. The same way of scoring is followed for the effect on absenteeism. We have considered converting scores like this into financial effects. Though basically possible, the amount in Euros is usually marginal compared to the effects on labor productivity. Similar scores are made for the effects on flexibility of personnel, of work processes and of the supplied care. Remaining aspects to be considered are:

- The extent in which patients (clients) are independent of care;
- the self development of employees;
- the attractiveness of positions;
- the attractiveness of the institution on the labor market.

Finally the group decides if the intervention is in line with the core values of the institution, e.g.:

- The intervention contributes to respect;
- the intervention contributes to autonomy of patients;
- the intervention enhances the innovative capacities of the organization;
- the quality of life is promoted;
- the intervention illustrates that health is essential.

Report and discussion on results

If all data are available, the internet tool provides a summary report (Figs. 14.3 & 14.4). The outcome shows the costs and benefits and other effects. The financial effects are provided for the situation in which the changes in labor productivity are fully cashed; this means that a reduction of required man hours is calculated as if that reduced workforce is no longer at work (fired, no longer hired). Especially in the health care, in many cases management and staff will not choose for that solution. It is more likely that extra tasks are performed (which may yield extra income or not), or used to reduce workloads. Some may consider this as a disadvantage of the analysis. We think that this is just the way management wants results. The next step after the analysis is the discussion on:

- Shall we implement the intervention?
- How will we deal with the options and effects?
- What should be changed in order to get an even better intervention?

3.4 An Example: A Fall Prevention Program

The institution is a nursing home for long term psychiatric patients, most of these are elderly. Three departments care a total of 61 patients. Some patients fall more or less frequently, several of them fall incidentally. Records show an average of 17 falls per 4 weeks that require at least help from nurses. One of these falls leads to hospitalization, followed by a week infirmary in the institution. The other falls have less serious or no injuries.

The task analysis shows that a total of 795 hours per year is spent as a result of falls. Several positions are involved in many different tasks: nurses, team leaders, physicians, physiotherapist, higher management, rehabilitation specialist.

With a program of preventive measures the aim is to reduce the number of falls with 30%. A plain calculation learns that such an effect would reduce the total hours per year by 240 hours.

To perform the preventive program, new routine tasks are required (Table 14.2):

Table 14.2: The fall prevention program's regular tasks

Task:	Duration per time	Frequency	Employees involved	Hours per year
Management of the program by a prevention team	45 min	6/year	5	23
Infrared alarm system detecting wandering patients	5 min	40/ month	1	40
Screening fall risk at admission	20 min	7/year	3	7
Discussion treatment plan	2 min	2/patient/ year	2	8
Extra screening on fall risk	20 min	2/month	3	24
Analysis of building and interior	30 min	2/dept/ year	1	3
Fall prevention on agenda of team meetings	5 min	2/dept/ year	1	88
Team leaders work on Patient's Incidence Reports	10 min	13/year	5	11
Total time in regular tasks				203

Investments: The development of the fall prevention program has required time of a program manager and 5 workgroup members, representing an amount of 11,115 Euros. Besides, two infrared sensors to detect patients that tend to fall at night are bought for 2,400 Euros. All staff is trained during one hour to become familiar with the fall prevention program (1,620 Euros). The total investments are 15,145 Euros.

It was decided that the investments should be debited in three years at an interest rate of 5.5%.

Investments in the building and the interior are of course costs. However, these are partly essential measures to provide safe care, and for the rest overdue or regular maintenance. These costs are paid from the central housing budget and are not charged to the departments.

Operational costs: The amortization costs are 5,048 Euros per year, the mean interest 555 Euros per year. The infrared senors need maintenance and energy, estimated to be 150 Euros per year. New staff needs to be trained in the fall prevention program: 6 nurses are trained 1 hour at 22 Euros per hour plus trainer costs, makes a total of 282 Euros per year. The total of the operational costs is 6,035 Euros per year.

Care quality: The group analysing the case has rated the effects on care quality. A representative of the patients took part in that discussion. The overall care quality improved from 57 on a 1–100 scale to 72. Aspects that improve are in particular:

- Fewer injuries caused by falls;
- actions on the basis of individual fall hazard analysis;

- fewer patients that need to be fixed with belts in bed or on chairs.

Other effects: The flexibility to organize the work improves as the number of fall incidents will be reduced by 30%. Fewer falls result also in less physical straining work to get patients on their legs or in their beds. The reduction leads to reduction of work stress and emotional stress.

The fall prevention program contributes to core values of the institution. Fewer people who need to be fixed with belts, is seen as more respect to patients. Helping patients to move safer enhances patients' autonomy. The quality of life of both patients and employees is certainly improved by fewer falls.

Over all effects: The fall prevention program benefits health of patients and employees. The quality of care is improved and a number of other positive effects are achieved.

There will be a reduction of working hours (37 hours per year). This reduction occurs in several positions and can happen during all working hours. It is most unlikely that a reduction of work force can be scheduled, and by doing so operational costs can decline.

As a consequence the increase of operational costs cannot be paid back by a reduction of labor costs. However, compared to the annual costs of the care of 61 patients, being 3 million Euros per year, the extra operational costs are fractional (less than 0.2% per year).

Cost Benefit Analysis

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Costs and benefits analysis

Name of the institution: Take Good Care
Department: Long term psychiatric care
Intervention: Prevention of falls with 30%
Date: 3 March 2008

Productivity

	Zero ass.	Virtual	Change	
Wages	19,743	18,917	-826	Euros/year
Effect on productivity	795	758	-37	Hours/year

Investments

	Zero ass.	Virtual	Change	
Development, consultancy	0	11,125	11,125	Euros
Purchases	0	2,400	2,400	Euros
Installation	0	0	0	Euros
Training	0	1,620	1,620	Euros
Total investments	0	15,145	15,145	Euros
Investment grants	0	0	0	Euros

Operational costs

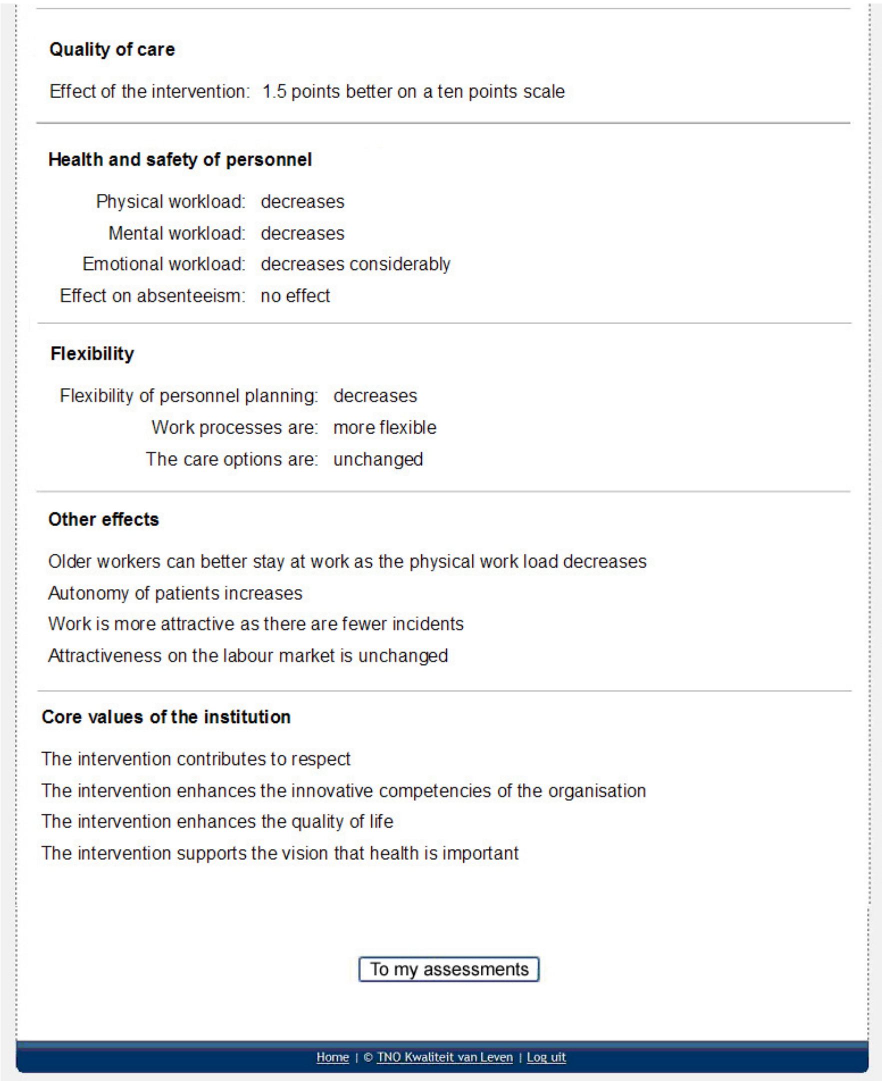
	Zero ass.	Virtual	Change	
Amortization costs	0	5,048	5,048	Euros/year
Mean interest costs	0	556	555	Euros/year
Maintenance	0	150	150	Euros/year
Consumables, energy	0	0	0	Euros/year
Other annual expenses	0	282	282	Euros/year
Income (if changed)	0	0	0	Euros/year
Total investments	0	6,035	6,035	Euros/year

Total effect on performance **€ 5,210** higher costs per year

In this effect is the reduction of time spent calculated at cost per man hour, which means that in fact the formation would decrease. In many cases institutions will not make that choice. Other options are:

a) Use the reduction of time for tasks that create new income.
b) Accept the extra costs per year, as the intervention has positive effects on e.g. care quality, workloads.
c) A mix of a and b. Reduce the formation to cover the extra operational costs, and spend the rest of the time for extra tasks or reduction of workload.

Fig. 14.3: Summary of results; the quantitative results of the analysis



Quality of care

Effect of the intervention: 1.5 points better on a ten points scale

Health and safety of personnel

Physical workload: decreases
Mental workload: decreases
Emotional workload: decreases considerably
Effect on absenteeism: no effect

Flexibility

Flexibility of personnel planning: decreases
Work processes are: more flexible
The care options are: unchanged

Other effects

Older workers can better stay at work as the physical work load decreases
Autonomy of patients increases
Work is more attractive as there are fewer incidents
Attractiveness on the labour market is unchanged

Core values of the institution

The intervention contributes to respect
The intervention enhances the innovative competencies of the organisation
The intervention enhances the quality of life
The intervention supports the vision that health is important

To my assessments

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Fig. 14.4: Summary of results; the qualitative results of the analysis

4 Ergonomics as a Profession

4.1 Who are the Ergonomists?

People who call themselves "ergonomist" or human factors specialist, can have many backgrounds. They may have a grade in industrial engineering, kinetics, biomechanics or human movement studies, industrial design, ICT, psychology, organizational design and management, safety, industrial hygiene, occupational nursing, or be an occupational physician. Most ergonomists have studied ergonomics as an extra to a more general profession. Even self-made ergonomists, who have developed themselves with courses and trainings, can be well functioning ergonomists. Though very democratic, for the profile of the expertise of ergonomics, this diversity is not supportive. Marketing hypes tend to identify ergonomics as contributing to "comfort" only. The more serious aspects of our work, preserving health and promoting human performance, are less displayed in shop windows.

Too much space for interpretation of ergonomics principles has led to statements that "if you have two ergonomists at the table, you may get three opinions". Better education and sound systems of professional certification can prevent these contra productive statements.

4.2 Education and Certification

Especially since the nineteen sixties the professionalism of experts in ergonomics and human factors enhanced. Courses in ergonomics and human factors started in a diversity of faculties, like psychology, human kinetics and industrial engineering. Some have grades in ergonomics or human factors.

The increasing choice forced faculties to improve their educations in order to survive in the ever changing academic structures.

The content of ergonomics may be important, skills and competencies are essential to act successfully as a professional ergonomist. The IEA promoted the development of educational programs, e.g. by defining minimum criteria. Over the years IEA has been publishing directories of educational programs in ergonomics, and an actual version is available through the Internet.

The creation of certification systems for professional ergonomists, and the core competencies that were defined in that respect, have been important for the profile of professional ergonomics. A worldwide generic system would have been good for the profile of ergonomics, but efforts to develop such would certainly have failed, due to differences in cultures, back grounds, and local regulations. The fact that many European countries agreed on one system (CREE), can be considered as a large step. Today, Australia, Canada, Europe, Japan, New Zealand and the US have well developed certifications for ergonomists; mutual acknowledgement of the systems was stimulated by the International Ergonomics Association.

In 2001 the International Ergonomics Association succeeded to state a world-wide accepted document on the core competencies of ergonomists, as well as criteria for IEA endorsement of certifying bodies (IEA WEBSITE). And in July 2006 the International Ergonomics Association's Council decided positively about a renewal of the IEA Code of Ethics (IEA WEBSITE).

The IEA is now developing criteria and requirements for ergonomics design of products, work systems and services. The proposed standard will be called: Ergonomics Quality In Design (EQUID) (EQUID WEBSITE). Such a standard is most important for the profile and status of ergonomics, and provides a backing for professional ergonomists and their clients.

Next to ergonomics competencies, the ability to tell benefits of ergonomics in core business indicators and to convince stakeholders with economic or other convincing arguments, has become increasingly important over the past years (KONINGSVELD 2006).

5 Conclusion

For long, ergonomics has been an expertise of people who were convinced of the need of prevention of health and safety at work, and/or human performance improvement. Most of them did ergonomics work next to their profession. The diversity of so-called ergonomists worked to a certain extent negative on the impact of the expertise. Besides, the broadness of their scope did not work well to profile of an expertise. Today we see much ergonomics work performed by people who don't use the words ergonomics or human factors at all; this happens in particular in ICT work.

The increasing quality of educations, the attention to core competencies and the creation of certification systems are important for the professionals in ergonomics. How many of the 18,000 members of the 43 ergonomics societies around the world are considering to be a professional ergonomist, is not known. We do know that there are many hundreds of certified ergonomists and human factors specialists. If these experts do their work well, and pay attention to the arguments with which they "sell" their findings, management and workers can easily be convinced of the need to organize and design work according to ergonomics principles. Ergonomist: be proud and show it!

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15 Effect Chains – A Method for Analysing Qualitative Effects in Occupational Health and Safety at Work

Martin Schmauder, Hanka Hoffmann

1 Introduction

The starting situation for activities related to health and safety at work in companies is characterised by a great deal of latitude for interpretation as regards the statutory outline conditions, with which companies respond individually to changes in the world of work and thus are able to open up potential in different ways. The flexibilisation of the world of work brings with it for example fresh demands on the skills and resources of employees. The intensification of work and expansion of responsibility leads to increased psychological stresses on employees. And not least, KRUEGER (2008) also highlights the significance of demographic change, particularly for SMEs: in the next two decades, we may anticipate an ageing (working) population across Europe. It is true that each worker ages differently, but the generally increasing mental and sensory deficits, above all the decrease in the capacity to adapt to changing circumstances, have to be compensated if even complex work tasks are to be performed through to pensionable age. Maintaining the health of employers is thus gaining increasing importance. This is achieved not only by avoiding or reducing absences, but by improving the state of health through improved conditions in the organisation, the work itself, and the development of personal qualities (Fig. 15.1).

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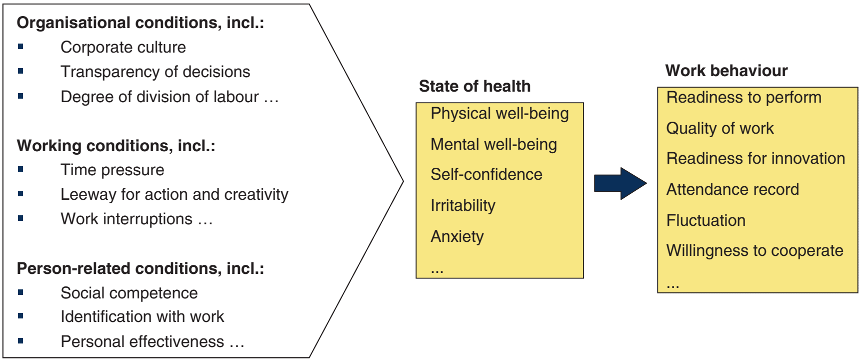

Fig. 15.1: Possible connections between organisation, work conditions, state of health and work behaviour. Source: based on B. Badura, in: BERTELSMANN STIFTUNG **(**2000, p. 25**)**

In the meantime, in accordance with the law on health and safety at work, in many companies workplace health and safety measures *and* health promotion measures are being implemented in order to safeguard human resources in a lasting way. These measures also contribute to a positive internal and external corporate image, as well as to service quality. The following illustration provides an overview of the problem areas and objectives that are most frequently addressed within the framework of company health promotion (Fig. 15.2).

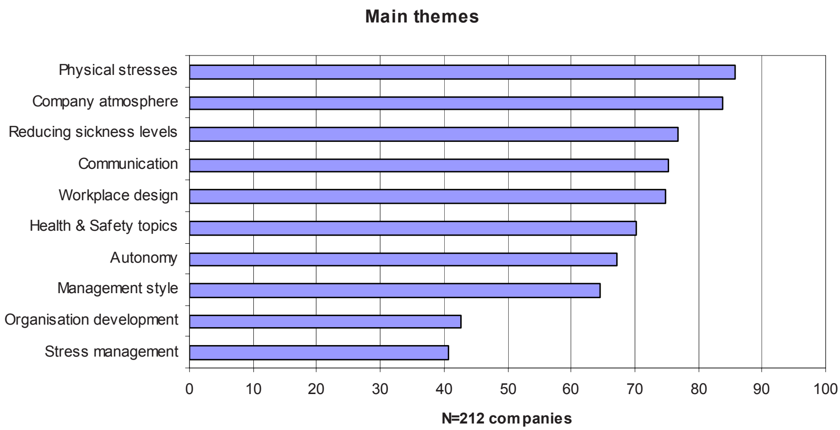

Fig. 15.2: Measures in contemporary health and safety at work and health promotion **(**AOK-BUNDESVERBAND 2007**)**

The spectrum of measures shows the breadth of contemporary health and safety at work, which includes health protection and health promotion. In addition to the question “How can illness be prevented?”, increasingly the question that is also asked is: "What needs to be done in order to preserve and improve the health of the workforce?"

If one wishes to record and represent the productivity of workplace health and safety, it is not enough to limit oneself to looking at just the pursuit of safety and health objectives and local optimisation of work systems. With the perspective of "results-oriented health and safety at work", the intention is to see the effects of workplace health and safety and health promotion services on the business results. The intention is that the overall benefit to the company can be illustrated, and that the contribution towards achieving diverse corporate goals is clear. We have "results-oriented" performance in health and safety at work and health promotion when these are shown to have contributed towards lowering overall costs or towards increasing the revenue of a company, and towards the long-term existence of the company by securing competitive product sales and by securing the necessary resources for adding value.

The need for concrete argumentation aids to illustrate the business economic benefits of preventive workplace health and safety is growing. The central question for companies – whether health and safety at work is worthwhile for them – can still only be answered unsatisfactorily (FROBÖSE et al. 2008, LANGHOFF 2002, BRAUN et al. 1999). In this respect, the method of effect chains attempts to close a gap in a practical way: health and safety at work and health promotion make a contribution towards improving profitability. This contribution cannot always be measured in monetary terms. However, with the aid of the effect chains method, the indirect effects can now be described plausibly, and the benefits of health and safety at work and health protection can thus be made clear.

2 The Principle of Effect Chains

On the one hand, the effects of measures in preventive workplace health and safety cannot always be determined precisely beforehand. On the other hand however, even in retrospect it is not possible to establish a clear relation between measures and effects. There is thus no proven causality between a measure and an effect.

So for example in the case of mechanical factors, causality is clear. If a protective grille is fitted at a feed point, injuries are avoided here. It is also undisputed that for example back problems are reduced by ergonomic measures, but one cannot say with certainty to what extent this is so, nor is it clear whether the ergonomic measures were the cause of this, or whether other effects played a role, too. The only thing that is undisputed is that the ergonomic measures have made a contribution towards reducing back problems.

It is precisely here where the method of effect chains comes into play. It is not a matter of identifying causal relations; rather, the diverse and interlinked effects of the workplace health and safety and health promotion measures are illustrated.

Effect chains are consequently complex constructions of causes and effects, as described for example by GOMEZ and PROBST (1995). In this sense, what is meant is webs of causes and effects, which take account of mutual influences and (interfering and encouraging) external influences. In such complex webs, effects themselves become causes, one cause can have many effects, just as one effect can have many causes. We describe these characteristics of the cause/effects web as multifinal and multicausal.

Workplace health and safety measures, too, have various effects. These effects in turn have other effects, which ultimately – in a positive case – are noticeable as effects that increase revenue or reduce costs (Fig. 15.3). Both have a positive influence on company profits (PIEPER & VORATH 2005).

Effect chains are accordingly intended to describe the contribution made by workplace health and safety and health promotion to the business result, and this can be differentiated via several sub-levels into partial indicators on both the revenue and costs sides.

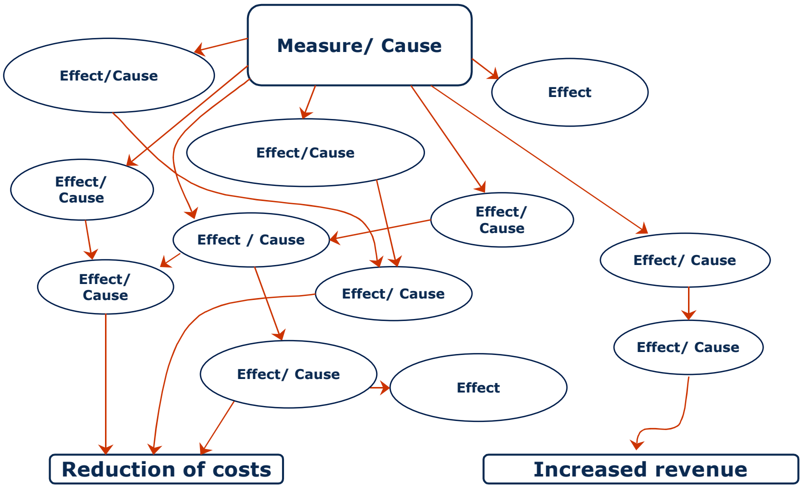

Fig. 15.3: Connections between causes and effects

3 Possible Uses of and Limits to the "Effect Chains" Method

As we have already explained, the "effect chains" method can be used to illustrate the effects of measures. It is therefore suitable for the following applications:

- Prospective application to work out goals and indicators prior to implementing a measure: Here, possible consequences can be estimated in the planning phase. Objectives can be established ("That is what we want to achieve in concrete terms!"). It is also possible to identify potential unwanted effects through prospective application of the method. Through the representation of the effect structure, aspects can be identified to which particular attention must be paid.

In general, it is possible at the start of the project to exchange views within the group about the objectives, to plan the measures, and to set priorities.

- Retrospective application to represent the observed effects: After workplace health and safety and health promotion measures have been implemented, a network of effects can be developed by means of the effect chains method. It is possible to show which positive (and also negative) effects a measure had, and how they are related. A contribution towards illustrating the benefits of the measure can be made here. However, no effects that are measurable directly in monetary terms are calculated here; rather, they are shown qualitatively. Since in general it is hardly possible to evaluate the success of workplace health and safety measures in monetary terms, it is precisely here that the strength of the method lies: It can be shown which benefits could be observed in the case of a concrete measure. When working out the effect chains, care must be taken to ensure that the effects that are actually observed are recorded. There is a risk that speculative effects, i.e. ones that are desired but did not actually occur, may be listed.
- The method provides stimuli for a structured exchange of opinions, and as an argumentation aid it can also form the basis for discussions about the effects of measures.
- Well-illustrated effect mechanisms enable the company to select the most suitable measures for achieving objectives, to optimise company procedures thereby, and to reduce the corporate risks in this connection.

The limits of the method lie in the fact that effect chains can also go nowhere or end up in dead ends. Furthermore, it is not possible to demonstrate the achievement of concrete goals in an evaluation process.

4 Participative Effect Chain Processing

Having explained the principle of effect chains, in the course of a brief look at the principles of facilitation we shall explain how effect chains in health and safety at work can be identified.

It is advantageous to work out effect chains in a facilitated team workshop. In practice, one finds typical discussion types which can be distinguished according to their objectives: In information discussions, the participants are to be instructed about something, given an overview, or receive instructions. In problem and decision discussions, solutions are worked out together, and measures are also coordinated. More interactions take place here, and also more emotion is shown. By contrast, the method of “effect chains” is more a form of brainstorming, in which ideas are found and above all experience can be gathered.

It is precisely in this quite open form of discussion that the role of the facilitator is of decisive importance. The facilitator leads a discussion and should simultaneously be a specialist in the methods of communication. The facilitator’s task lies in leading the group to a result by using appropriate methods, during the course of which he directs the process methodically but remains neutral as regards content.

Besides the actual content of the individual contributions, he must also take account of the relationships between participants, which can have an enormous influence on the result of a discussion (WATZLAWICK et al. 1974). It is therefore advantageous if the facilitator assumes an independent position in relation to the participants – in the case of analysis of the effect chain, he acts as an external party in the company. He should know about the 4 aspects of a message (factual information, appeal, reference and self-disclosure) (SCHULZ VON THUN 1981) and also must not underestimate group dynamic processes.

In its discussion, a group brings to light more than the sum of its individual members. DAMMER and SZYMKOWIAK (2008) go so far as to say that "the whole *is more than and different from* the sum of its parts" (p. 30). This "more than and different from" results from the group dynamic, from that which the group conveys non-verbally or scenically in terms of content, and ultimately from the greater breadth and unity of the work on the topic, simply through mutual stimulation and reflection in the group.

The starting point for the effect chains workshop is a workplace health and safety or health promotion measure that has actually been implemented or planned. It is important to include representatives of all the protagonists involved in the measure in the group discussion, in order to depict the cause/effects web from different perspectives and thus as completely as possible. The various perspectives of the participants give rise to various expectations and aims. All have an entitlement and are part of the system to be dealt with. Gomez and Probst therefore suggest, in the spirit of a holistic procedure, putting together an interdisciplinary group of people with expertise, in order jointly to describe connections and/or to derive suitable possibilities for action. They also refer to the ethical aspect of such a procedure – including all legitimate interests in so-called claim group teams right at the start of a holistic problem-solving process (GOMEZ & PROBST 1995).

The formulation of the problem is important for the success of an effect chains workshop. What we mean by this is the initial question with which the participants are confronted. This should be considered carefully as a preliminary step – a good question is decisive for a good result. The question serves to prompt the participants to express everything that they would like to express – in other words, to set the process of finding the effect chains in motion. Each contribution is important here, and can stimulate the other participants to discussions or other contributions. In order for a complete network of effects to be depicted, all contributions need to be visualised.

Three steps follow on from the initial question:

1. Requesting anonymous cards, with pin-board technique

In the most favourable case, the participants in an effect chains workshops are very heterogeneous, including as regards the position of individual people within the hierarchy (see above). Although this is important for producing a complete representation of all effects, it is precisely because of this that difficulties can arise at the start of a brainstorming session. For this reason, the written form of brainstorming – so-called brainwriting, or requesting cards – is more appropriate in this phase. The advantage here is that a great deal of information can be assembled within a short space of time, and possible inhibitions on the level of relationships or losses through production blocks (DIEHL & STROEBE 1991) are excluded. For example, the contributions made by a shy colleague are collected in the same way as those of an eloquent superior, something which cannot necessarily be achieved when such a procedure is carried out verbally. All the participants write down in parallel their experiences and opinions concerning the problem defined at the outset on cards (one aspect per card). It must be specified beforehand whether the number of cards is to be limited, which on the one hand restricts creativity, but on the other hand ensures a manageable quantity of cards.

The cards are collected in by the facilitator and pinned to the display board. Cards whose contents are similar are grouped together (thematic clusters) with the aid of the participants. Writers of cards can remain anonymous. Cards can be supplemented during the discussion, too. In the discussion, generic terms are sought for thematic groups, which can be used for further work.

2. Guiding questions

In the second step, with the aid of the generic terms the web of effects is worked out. For this, we use a system of co-ordinates (Fig. 15.4). The use of this procedure is intended to achieve comparability of different group discussions. In the system of co-ordinates, those factors are shown which – according to our understanding, based on DAMMER and SZYMKOWIAK (2008) – ensure functional representativeness of the results of the survey.

Based on the system of co-ordinates, and starting from the generic terms found in the first step, by means of guiding questions additional observed or suspected effects are determined and placed in relation to one another. Here, visualisation in the form of a mind map can be helpful (main branches with offshoots and secondary offshoots).

Particular importance is accorded to the questions about the effects on the participant. In the sense of the theory of planned behaviour (AJZEN & FISHBEIN 1980), behaviour can change only if as a preliminary step, the intention and its predictors “attitude to a particular behaviour” (the sum of expectation and evaluation), “subjective norms” (corresponding to the social pressure that people close to the person exert in relation to the performance or non-performance of the particular behaviour), and “perceived behaviour control” (a person’s conviction about how easy or difficult a behaviour is for him to carry out). For workplace health and safety measures, this means that they have to act on precisely those predictors, in order ultimately to achieve a change in people’s behaviour. According to Ajzen, action that takes account of workplace health and safety must be assessed positively by the person himself and must be assessed as easy to implement. Furthermore, the person has to believe that other people who are important to him likewise assess the performance of this behaviour positively. Depending on how far-reaching the effects of workplace health and safety measures are, they will also result in long-term changes in behaviour.

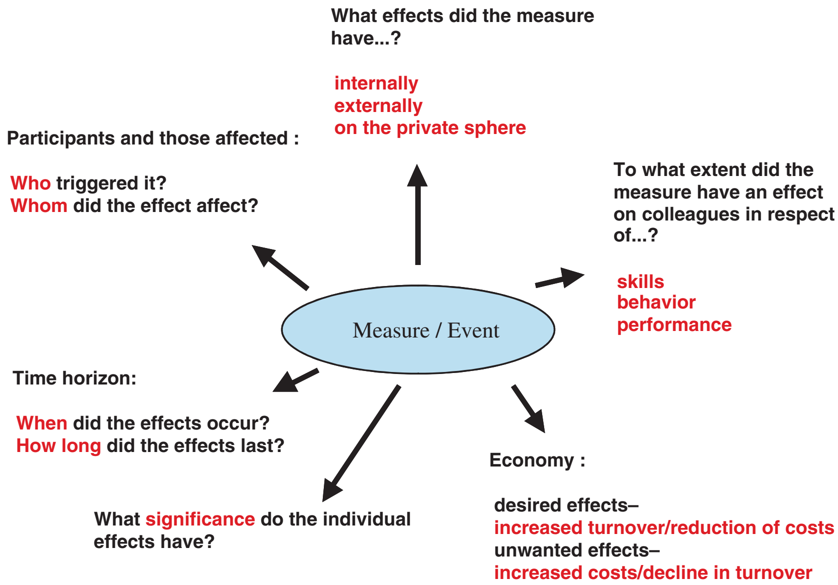

Fig. 15.4: System of co-ordinates for producing functional representativeness

The following example guiding questions originate from a workshop carried out by the trade association for health provision and welfare (BGW). With representatives from hospitals and clinics that took part in the competition "BGW health prize 2005", effect chains to represent the benefit of workplace health and safety and health promotion measures in hospitals and clinics were worked out.

The facilitator names the measure under consideration, and asks for example:

- What was different afterwards?
- What happened then?
- What effect did that have
    - externally (society, customers)?
    - internally (colleagues, other departments, administration)?
    - on the private sphere/family?
- Do outsiders notice any of this?
- Have there been any effects on other areas?
- Have there been any effects on the company as a whole?
- What has changed in:
    - work tasks, workplaces/premises, work tools, work procedures, working environment (physical, social)
    - ecology

- o safety
- o behaviour?

The respective answers are visualised in turn. The following illustration shows an example of this (Fig. 15.5).

Fig. 15.5: Example of visualisation when working out effect chains

When an effect has been identified, then additional effects are requested, so that a network of effects is produced. When identifying additional effects, the same questions can be used, but one can also ask for example:

- What can be deduced from that?
- What else resulted (additional effects)?

The individual effects are placed in relation to one another and linked with arrows, which at the end will ideally lead to the field “Reduction of costs” and/or “Increased revenue”.

3. Weighting by means of points

For the purpose of structuring, finally the main effects of a workplace health and safety measure are identified, in that the workshop participants apply adhesive spots (e.g. 3, a maximum of 2 on one effect) to the effect which in their opinion is the strongest. This last work step, which creates transparency, makes sense, since it is only in this way that a measure can be evaluated in terms of its content, and the results that have been achieved can be compared with the actual goals of workplace health and safety at the company.

5 Application of the Method – Experience so Far

In our experience, effect chains workshops are successful where the event that is to be discussed lies no more than 2 years in the past.

The discussion takes place within the framework of a 90-minute facilitated workshop.

Allowing for complete representation of the protagonists, group size should be between 8 and 12 people. Smaller groups do not provide sufficient "anonymous protective space", and larger ones are no longer suitable for getting the group members to talk to one another and discuss a common topic.

The event is facilitated by two facilitators, ideally male and female. Co-facilitation is necessary in order to be able to fulfill all the requirements with regard to visualising the discussion during the workshop, and to provide adequate documentation of the contextual facts of the discussion in the facilitator logs, whilst simultaneously guiding the discussion in a satisfactory manner. The co-facilitators switch between the roles of guiding the discussion and taking minutes at least once in the course of the discussion.

6 Examples of Effect Chains

Two examples of effect chains are shown below. These effect chains were worked out, amongst many others, in the BGW workshop mentioned above, and in the framework of the PAGSmonitor project. The first effect chain shows the diverse effects in connection with back training (Fig. 15.6).

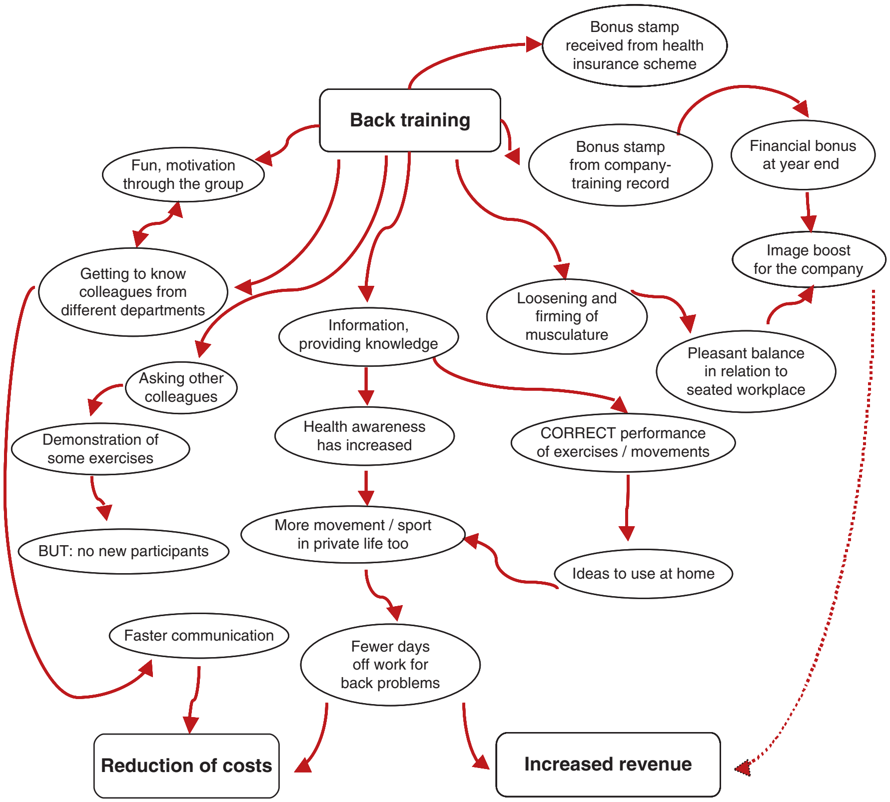

Fig. 15.6: "Back training" effect chain

The second effect chain documents the interlinked effects that can be established as the result of carrying out a health day (Fig. 15.7).

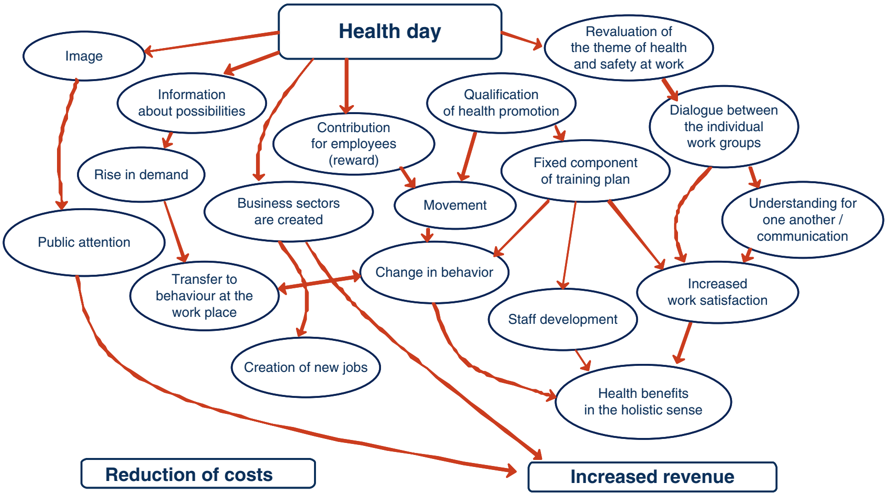

Fig. 15.7: "Health day" effect chain

7 Conclusion

With the "effect chains" method, a method is presented for representing the benefits of corresponding measures that is new in health and safety at work and health promotion. What is new is that the previous approach of assessing the workplace health and safety and health promotion measures in purely monetary terms is replaced by a qualitative illustration of the effects. This is associated with goal-oriented company management. Using the method, it can be shown that health and safety at work and health promotion make an active contribution to the achievement of corporate goals. The method is also suitable for the planning and optimisation of workplace health and safety and health promotion measures. It can be used in small groups, and creates transparency in discussions about the effects of measures within the company.

The method is currently being used and developed in the project PAGSmonitor: Economic health and safety at work through benchmarking. Thus for example the relations between the individual effects, based on GOMEZ and PROBST (1995), should be described in greater detail in three respects:

- According to their time horizon: do they act over the short term, medium term or long term (lines of different thicknesses or colour of arrows)?
- According to their intensity: is the influence weak (1), moderate (2), or strong (3)?
- According to their effect: reinforcing (+) or damping or stabilising (–). It is possible to indicate the strength of influence by means of arrows of different thicknesses.

The research project PAGSmonitor: Economic health and safety at work through benchmarking runs until September 2009 and is supported by the Federal Ministry of Education and Research.

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16 Multi-Perspective IT Evaluation Tool for Shift Schedules

Peter Knauth, Patric C. Gauderer, Kathrin Elmerich, Dorothee Karl

1 Introduction

The term "shiftwork" may refer to working either at "various times of day" (e.g. morning, afternoon, and night shift) or at "constantly unusual times" (e.g. permanent night shift, permanent afternoon shift).

Shiftworkers may encounter a number of problems, such as living against their biological clock, sleep disturbances, tiredness, lack of appetite, impaired performance, interferences with their family and social life and even diseases such as gastrointestinal or cardiovascular illnesses (KNAUTH 2008). To reduce these negative effects, the German Working Time Act (Art. 6 Par.1) demands that "the working hours of night and shiftworkers shall be regulated on the basis of sound ergonomic knowledge about the humane design of working conditions."

However, many shift systems that do not meet this legal requirement are still being used in the Federal Republic of Germany. As workforces are growing older due to demographic change, and as the legal retirement age has been increased to 67, more and more corporate executives are beginning to wonder how the work ability and health of their employees can be maintained or even improved. As part of a more comprehensive strategy (KNAUTH et al. 2009), the design of working hours and, more importantly, ageing-appropriate shift systems are of great importance.

A shift schedule may be regarded as "ageing-appropriate" if it first conforms to ergonomic recommendations; second, provides adequate rest periods; and third, permits a certain degree of employee-oriented flexibility, such as choice of working hours (KNAUTH 2007).

It was one of the objectives of the KRONOS research project under which life working-time models were developed, introduced, and evaluated to develop, in cooperation with an automobile company, a user-friendly IT tool for evaluating existing or planned shift systems.

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2 Requirements Applying to New Shift Schedules and the New Tool

There is no such thing as “the optimum” shift system. At each plant operated by one and the same enterprise, the objectives pursued in the design of an appropriate shift system may vary widely. Moreover, the expectations and needs of various employee groups may differ depending on their composition (e.g. in terms of age, marital status, children, nationality, place of residence, leisure activities, state of health). Ergonomic recommendations aim at avoiding and/or reducing any impairment of health, well-being, work ability, and social life in the family and beyond.

In designing a “tailor-made” shift system, legal and local framework conditions need to be taken into account as much as ergonomic recommendations on shift schedule design and the preferences of the shiftworkers concerned.

Beyond that, the principles of dialogue design and the serviceability requirements laid down in DIN EN ISO 9241 had to be taken into consideration when the new tool was developed.

3 Preparatory Activities

3.1 Analysis of Existing Tools

At present, the following IT tools are available for the ergonomic evaluation of shift systems:

(1) BASS 4.0 (NACHREINER et al. 2005)
(2) OPTISCHICHT (FERGEN et al. 2006)
(3) Rota Risk Profile Analysis RRPA (JANSEN 1990, JANSEN & KROON 1995, JANSEN & BAAIJENS 2007).

(Ad 1) BASS 4.0 is a complex tool (the manual comprises almost 300 pages) for developing and evaluating shift systems that was developed by Prof. Dr F. Nachreiner and associates (www.gawo-ev.de).

(Ad 2) OPTISCHICHT is a PC programme for developing and evaluating shift systems that was developed by Dr W. Schweflinghaus at the Medical Psychology Institute (MPI) of TÜV Nord Mobilität GmbH & Co. KG, Essen (www.optischicht.de). Background knowledge is helpful in interpreting the results.

(Ad 3) Rota Risk Profile Analysis (RRPA) is a shift system evaluation programme that was developed by Dr B. Jansen in 1990 and refined later on (JANSEN & KROON 1995, JANSEN & BAAIJENS 2007). There is no German-language version of the programme (www.Dehora.nl).

While all major ergonomic criteria for shift system evaluation are taken into account by the three programmes named above, employee preferences are disregarded.

3.2 Shiftworker Survey

Since the tool described below was developed in cooperation with a company from the automobile sector, it was the employees in one of the company's production facilities who were interviewed about their preferences. Age distribution among the male interviewees (n = 104) was as follows:

- 13.5% 21–30 years
- 26.9% 31–40 years
- 42.3% 41–50 years
- 11.5% 51–60 years

82.7% were living in a partnership and 51% had children, generally 1 or 2. 77.9% had no executive function and 72% had been doing shiftwork for more than 15 years.

Among other things, interviewees were asked to assess the importance of the major shift system characteristics under the aspects of family, leisure, and health, using a scale of five ratings ranging from "wholly unimportant" to "very important". As the family and leisure aspects were almost congruent, they were analysed together in the subsequent evaluation. Results were later used to weight ergonomic criteria (Fig. 16.1).

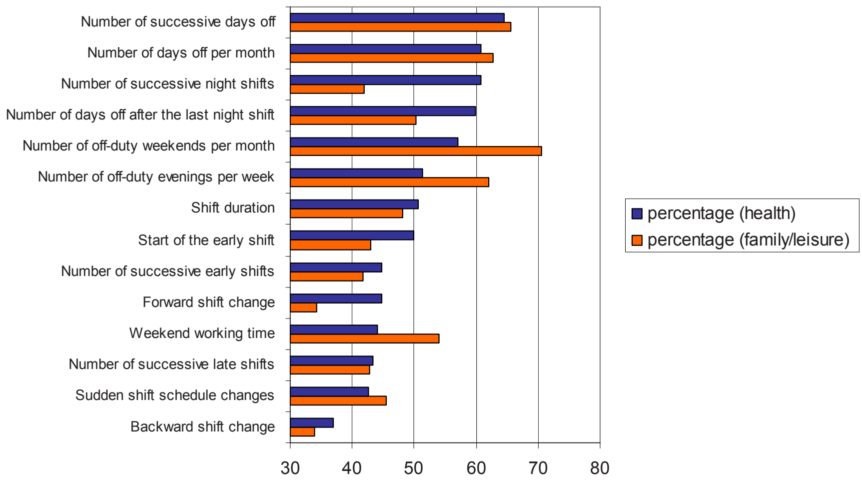

Fig. 16.1: Weighted significance of ergonomic citeria [%]

4 Description of the Evaluation Tool

The evaluation tool was written in Microsoft Excel because this system permits translating applicable requirements quickly into a usable product. Moreover, as Excel is used in many enterprises, users are familiar with the handling of the programme, and the amount of additional hands-on experience needed is not so great. If necessary, experienced users may even be trusted to modify and/or adapt the programme to specific company requirements. Not least among the advantages of this procedure is that it simplifies passing on new programme versions. At the same time, signatures may be used wherever necessary to ensure that only those versions of the application are actually used that were released and authorised before.

In developing the tool, one of the objectives was to ensure a maximum of usability in day-to-day use. For this reason, the application was designed to permit users to work mostly with familiar routines and operating concepts. More importantly, using the programme does not call for extensive familiarity with ergonomic fundamentals, so that shift systems may be evaluated even by employees who do not have any special training. However, any in-depth interpretation of results that may be needed should be done only by experts, especially where shift plans are concerned that are judged to be highly unfavourable. Similarly, trained employees should be called in whenever shift schedules need to be redesigned or developed from scratch.

Each of the steps involved in shift schedule evaluation has been mapped on a separate spreadsheet. Originally empty, these spreadsheets will be filled in by users, going from item to item until the evaluation step is reached. The algorithms needed for the evaluations themselves have been implemented in “Visual Basic” and linked to the respective spreadsheets. They are activated by buttons integrated in each spreadsheet.

In the following, the spreadsheets contained in the application will be explained together with the individual steps of the process.

4.1 Preparations

Before work with the evaluation tool can begin, the shift schedule to be analysed should be on hand. Next to the sequence of shifts and off days, it should specify the working hours on which the shifts are based. Shifts should be classified as morning, evening, and night shifts.

Each shift system is evaluated individually in its own Excel file. To begin with, therefore, a copy of the current version is created and named after the system to be evaluated. This copy is then opened with Excel.

4.2 Data Input

The process of evaluation begins with the “Data Input” spreadsheet on which the user enters all items of information relating to the shift schedule (Fig. 16.2).

	Enter shift type / times			Number of shift groups	Shift rhythm (number/weeks)
	Early shift F	Late shift S	Night shift N		
from	06:00	14:00	22:00	5	30
to	14:00	22:00	06:00		

Enter | Enter | Delete entry

Team	1							2						
	Mo	Tue	We	Th	Fr	Sat	Sun	Mo	Tue	We	Th	Fr	Sat	Sun
1	M	M	M	M	M	M	off	off	off	off	off	off	off	off
2	E	E	E	E	off	off	M	M	M	M	M	M	off	off
3	N	N	off	off	E	E	E	E	E	E	off	off	M	M
4	off	off	N	N	N	N	N	N	off	off	E	E	E	E
5	off	off	off	off	off	off	off	off	N	N	N	N	N	N

Team	3							4						
	Mo	Tue	We	Th	Fr	Sat	Sun	Mo	Tue	We	Th	Fr	Sat	Sun
1	N	N	N	N	N	N	off	off	E	E	E	E	E	E
2	off	off	off	off	off	off	N	N	N	N	N	N	off	off
3	M	M	M	M	off	off	off	off	off	off	off	off	N	N
4	E	E	off	off	F	F	F	F	F	F	off	off	off	off
5	off	off	E	E	E	E	E	E	off	off	M	M	M	M

M = morning shift
E = evening shift
N = night shift

Fig. 16.2: Tool: Input spreadsheet

Working times must be entered according to the shift type (morning, evening, or night shift) that appears on the shift rota. If any shift type does not appear on the shift schedule, the corresponding input fields will remain empty. Further items to be specified include the number of shift groups and the shift cycle in weeks. Once this input operation is completed, the shift system may be unrolled by clicking on the “Enter” button. The spreadsheet will show an empty schedule bearing the desired number of weeks and working groups.

Next, the sequence of shifts and off days is entered in the schedule under investigation.

To simplify data capture, a company-specific upgrade has already been implemented which permits importing existing shift schedules from the plant database.

4.3 Definition of Priorities

Ergonomic evaluation is founded on 11 criteria with 15 distinct specificities (Fig. 16.3). In the analysis of the shift schedule which constitutes the next step, conformance or nonconformance with each criterion will be determined.

Ergonomic criteria	Specific criteria	Priorities A(PA)	Priorities B(PB)
Maximum number of successive identical shifts	As few successive night shifts as possible	60,71	41,85
	As few successive early shifts as possible	44,86	41,78
	As few successive late shifts as possible	43,29	42,78
Rotating shifts	Forward change	44,86	34,28
Special shifts	Minimum 2 days off after the last night shift	59,86	50,21
	Avoid working days sandwiched between days off	51,28	48,12
Maximum number of successive working days	Five to seven working days maximum	51,28	48,12
Shift duration	Avoid long working shifts, observe rest periods	50,71	48,21
Start of early shift	Not too early	50	43,07
End of late shift	Not too late	51,28	48,12
End of night shift	As early as possible	51,28	48,12
Weekend work	Avoid weekend work; blocked free weekends	57	70,57
Initiated by employer	Avoid sudden deviations; observe minimum warning periods	42,71	45,42
Time off	Average number of successive days off in the shift rhythm	64,57	65,57
	Number of evenings off per week	51,29	62,06
		Share in final result	**Share in final result**
		70%	30%
	Employee preferences · Add to priorities A · Add to priorities B		
	Priority characteristics family /leisure · Add to priorities A · Add to priorities B	PA --> S1 / PA --> S2	PB --> S1 / PB --> S2
	Priority characteristics Health · Add to priorities A · Add to priorities B		
	No priority use · Add to priorities A · Add to priorities B		

Fig. 16.3: Tool: Criteria Definition spreadsheet

As the requirements applying to a shift schedule may vary depending on the respective point of view, user-definable weighting coefficients are assigned to each result of the ergonomic review. As many as two weighting coefficients may be specified for each criterion.

The weighting coefficients themselves are defined on the "Priorities" spreadsheet, giving the user an opportunity not only to weight every single criterion according to his or her individual requirements but also to specify two catalogues of weighting coefficients at the same time. These, in turn, may again be assigned different weighting coefficients for the determination of the final result. Assuming, for example, that one catalogue of priorities has been created which focuses on health criteria and another which focuses on social aspects, these may be given weights of 70% and 30%, respectively, when the final result is calculated. An alternative option is to evaluate the schedule on the basis of no more than one catalogue of criteria, which will then be given a weight of 100%.

The application comes with three predefined catalogues of weighting coefficients. The coefficients in the first catalogue are based on employee requirements derived from the results of an employee survey (s.a.). Use of this catalogue ensures that the special requirements of the workforce are taken into account in the evaluation of a shift schedule.

The two other catalogues of weighting coefficients concentrate on the effects of a shift schedule on health and family/leisure, respectively. In addition, a schedule may be evaluated without the use of weighting coefficients, in which case all criteria will have equal status in the analysis.

These predefined weighting catalogues may be transferred by the user in one of the two prioritisation blocks with the aid of buttons integrated in the spreadsheet.

Alternatively, the user may enter any weighting coefficients in addition to those contained in the predefined catalogues.

To examine the impact of different weighting coefficients on the final result, the user may store recently created coefficients in a buffer. Using this option is especially recommended whenever plant-specific weighting coefficients have to be defined. In this case, the results of each evaluation may be discussed in local working groups and standard weighting coefficients defined that apply to the site.

If the application is to be commonly used to analyse shift schedules within a plant, a standard catalogue of weighting coefficients should be used to ensure that results remain comparable.

4.4 Evaluation of the Shift Schedule

The "Evaluation" spreadsheet (Fig. 16.4) is used to evaluate shift schedules.

Ergonomic criteria	Recommendations	Current value/ current number	Evaluation
Maximum number of successive identical shifts	As few successive night shifts as possible (max. 3) avoid uninterrupted night shifts	6	
	As few successive early shifts as possible (max. 3)	6	
	As few successive late shifts as possible (max. 3)	6	
Rotating shifts	Forward change	Backward	
Special shfits	Minimum 2 days off after the last night shift (N, off, off, F)	-1	
	Avoid working days sandwiched between days off	OK	
Maximum number of successive working days	Maximum five to seven working days	6	
Shift duration	Avoid long working shifts (>8h), observe rest periods (min. 11h)	OK	
Start of early shift	Not to early (i.e. 6:30 better than 6:00, etc.)	6:00	
End of late shift	Not too late (i.e. 22:00 better than 23:00, etc.)	22:00	
End of night shift	As early as possible	6:00	
Weekend work	Avoid weekend work; blocked free weekends (average per week)	1 ½	
Initiated by employer	Avoid sudden schedule changes and working-time agglomerations, match shift length to workload	----------	----------
Time off	Average number of successive days off in the shift rhythm	3,93	
	Average number of evenings off per week	4,20	

Evaluation A:	2,28	70%
Evaluation B:	2,12	30%
Total evalutation	2,23	100%

bad result / urgent need for action

neutral result / need for action

good result / no need for action

Start evaluation

Fig. 16.4: Tool: Evaluation spreadsheet

The configuration of this spreadsheet resembles that of the preceding one. Once again, it shows the criteria that will be used in the analysis. The examination of the shift schedule that has been entered will begin as soon as the user clicks on the "Start Evaluation" button. The first step will be to determine the results under each individual criterion.

To give the user an opportunity to check the rating of the shift schedule under investigation with regard to specific criteria, this is shown on the spreadsheet next to the criterion in question. In addition, the “Recommendations” column shows the values that make sense from the ergonomic point of view (KNAUTH 2005). Nevertheless, the values that have been determined and are shown on the spreadsheet are difficult to interpret for users without the requisite ergonomic background. To enable such users to put the results of individual criteria into perspective and identify weak spots in the schedule, a signal system has been integrated in the application. The cell immediately next to the value determined will be highlighted in red, yellow, or green, indicating whether the result is bad, neutral, or good. Therefore, if a cell highlighted in red shows next to a specific criterion, it is highly probable that action will have to be taken in this area. This signal system may also be configured on a site-specific basis. Users may preset an exact range of values for each colour. A dedicated spreadsheet is available for entering these parameters which, however, will not normally be accessible to ordinary users not only because these modifications call for specific background knowledge but also because the results of a shift schedule analysis may become unusable if a faulty configuration is entered.

The values shown in the upper segment of the evaluation spreadsheet are based on ergonomic recommendations, reflecting a view of the shift schedule that is independent of user and plant-specific requirements.

This being so, the next step of the analysis is to weight the values determined using the priorities preset on the preceding spreadsheet. The results thus obtained are similarly shown on the spreadsheet together with the relevant weighting coefficient for the final result. Lastly, the final result of the analysis will be computed.

Weighted values range from 1.0 (very good) to 3.0 (very bad). Once again, the signal system described above is used so that the results presented can be judged quickly.

The complete shift schedule under investigation is shown on the first spreadsheet. This being so, subsequent steps to improve an existing schedule can be carried out directly in the analytical tool. Experimental modifications implemented in the schedule can be analysed directly and their effects documented. In this way, existing schedules may be improved in an iterative process, a method which may also be employed, for example, in relevant workshops.

5 Conclusion

Not only does this new tool for evaluating shift schedules, like other existing tools, take ergonomic recommendations on shift schedule design into consideration, it also considers the preferences of the employees concerned. Already proven in the field, the new tool is being used at all production facilities of an automobile company under the name of “ABA Shift”.

As acceptance problems are to be expected whenever a shift schedule is changed (KNAUTH & HORNBERGER 2000a), the use of an IT tool should always be embedded in an adequate introduction strategy featuring, for example, information, communication, and the involvement of all concerned (KNAUTH & HORNBERGER 2000b).

Ageing-appropriate shift schedule design will be fully effective only if integrated in all overall strategy which includes, among other aspects, management sensitisation, ergonomic workplace design, ageing-appropriate in-service training didactics, systematic accumulation and transfer of experience, and health promotion (KNAUTH et al. 2008).

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17 Organizational Change and Occupational Health – Towards a Resource-Based Change Management

Karlheinz Sonntag, Alexandra Michel

1 Introduction

1.1 Driving Forces of Organizational Changes

Today's work is characterized by ongoing change processes. Although this is not a new phenomenon, there are signs, that these changes accelerate, become more important and vary in intensity, duration and frequency. Diverse trends in economics, politics and technology put pressure on organizations to optimize both their strategic position and their business performance (see Fig. 17.1). Four perspectives can be captured to classify these trends:

- *Competitors:*
  Organizations have to compete with global players, characterized by an optimized value chain and innovative business models. Ongoing need for consolidation leads to raising numbers of mergers and acquisitions.
- *Customers:*
  Customers have high expectations and requirements regarding quality, pricing and delivery time of products and services. In addition, the distribution of products and services by the internet and the associated transparency enforces customers' negotiating position.
- *Capital markets:*
  For most organizations capital markets provide essential financial sources. In turn, actors in the capital market have high expectations on organizational profitability and growth. As a result, organizations are often asked to reorganize to meet these expectations.

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- *Dynamics of the environment:*
  Frequent technological innovation as well as changing markets caused by deregulation and privatisation put organizations in a very dynamic environment, in which successful adaptation is highly demanding.

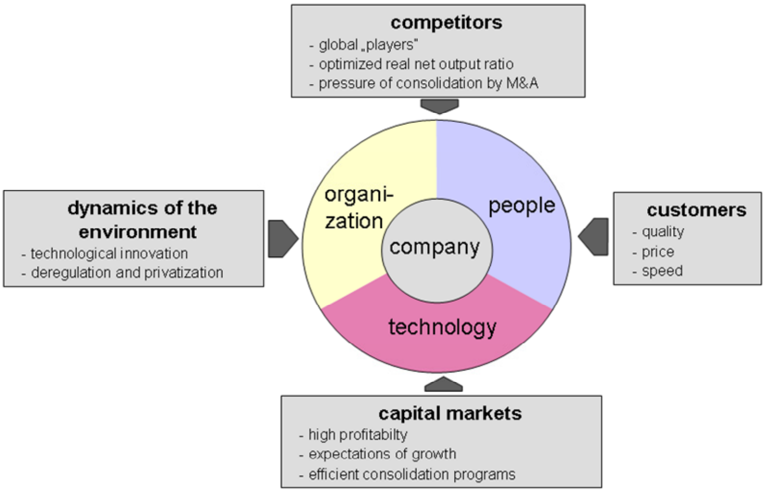

Fig. 17.1: Factors of company performance

Change processes do not only affect employees of industrial organizations, but also members of non-profit organizations, e.g. public administration and universities (MICHEL et al. 2009, SONNTAG et al. 2008). In contrast to change research from an applied economics perspective, work and organizational psychology research focuses on employee adjustment to organizational change: Restructuring on the side of the organization always goes along with changed experiences and behaviour on the side of the employees. As can be seen from recent reviews (LUCZAK et al. 2002), occupational health research is asked to take these developments into account. The focus should be on practical implications of resource-based psychological approaches to occupational safety and health (SONNTAG 2001).

1.2 Challenges in Managing Organizational Change Processes

Organizational changes pose challenges both for executives and employees: Work routines have to be reassigned, new processes, products or tasks have to be implemented within short time and recently reached decisions have to be revised. Persons involved in organizational change are likely to undergo mixed experiences such as tension, hope, worries, fear and frustration. In one of our studies 1150 executives from the automotive industry sector were interviewed (SONNTAG & SPELLENBERG 2005). Results revealed eight challenging areas (see Fig. 17.2).

Fig. 17.2: Stumbling blocks of change management (SERO-study, SONNTAG & SPELLENBERG 2005)

As a matter of course these challenges are not only restricted to this industry sector, moreover they are likely to emerge in all sectors were pivotal changes influence daily business:

- *Amount of change-projects:*
  61% of executives specify that there are too many change projects in their organization at the same time. Due to pressure of a highly competitive environment, organizations aim to improve their strategic and functional position which is reflected in a high amount of ongoing change processes. Furthermore, personnel changes in the top management often result in organizational restructuring.
- *Compatibility of change projects:*
  61% of the executives indicate that change projects are not part of a comprehensive change strategy. This is reflected by inconsistent goals, poorly adjusted milestones and unscheduled development of business solutions and concepts.
- *Adequate handling of changes:*
  61% of executive staff state the difficulty in managing change projects in an adequate and effective way. In many cases restricted personnel resources complicate the successful implementation of change processes. Employees have to bear the challenge combining project work with their daily routines.
- *Communication of change:*

Furthermore, 68% of executives indicate that most change processes lack sufficient communication. As a result, most employees do not understand the causes, benefits and aims of organizational change projects. Inconsistent and delayed information can contribute to a feeling of change-specific insecurity.

- *Consistency, sustainability, meaningfulness and participation:*
  Finally, more than half of the respondents specify that they have difficulties in recognizing consistency, sustainability and meaningfulness of ongoing change processes. 70% also indicate that there are no or only reduced possibilities to participate in change processes. The lower the level within the management hierarchy the less executives perceive opportunities to participate.

In this study, executives were also asked to comment on the resources that should be used to support organizational changes. Results from these expert-interviews are displayed in Fig. 17.3.

resources in management	resources in culture and structure	job-related resources
participation/involvement (92,5%)	meaningfulness of change processes (92,3%)	potential of qualification (77%)
benevolence/loyalty (92%)	information and communication (80,8%)	adequate density of tasks (76%)
support (88,5%)	consequence and sustainability (76,9%)	challenging tasks (69,2%)
open and honest communication (80,8%)		latitude (61,5%)
competence (53,8%)		money (53,8)
consistency (46,3%)		status (50%)

Fig. 17.3: Which resources support change management? Results of the expert-interview (SERO-study)

As can be seen from this figure, resources in management, organizational culture and structure as well as job-related resources support the implementation of change processes. In particular the following resources can promote successful change management:

- Participation and involvement of executives in intended organizational changes
- Communication of meaningfulness, sustainability and continuity of change processes

- Perceived organizational support, based on a trustful relation with one's supervisor
- Sufficient job-related resources, e.g. latitude and adequate density of tasks.

1.3 Relation Between Resources and Willingness to Change

Besides investigating challenges and resources in the context of organizational change in the automotive industry sector, relations between perceived available resources and executives' attitudes towards organizational change have been examined in this study.

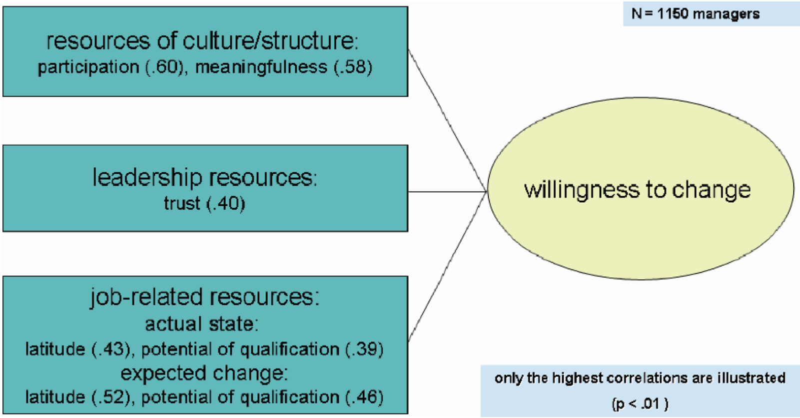

Fig. 17.4: Relations between available resources and willingness to change (SERO-study)

Results indicate positive correlations between resources and willingness to change (see Fig. 17.4). In particular, resources concerning change culture and structure, such as participation and meaningfulness, were significantly positively related to willingness to change. Furthermore, results show a significant positive relation between job-related resources like latitude and potential of qualification and this outcome. Focussing on the role leadership resources play in relation to willingness to change, a significant positive correlation between trust in management and this change-specific attitude has been found.

2 Ways to Analyse Strain and Resources in Organizational Change Processes

Executives and employees are more likely to positively adjust to organizational change, if they recognize and use available resources. Within the context of organizational change, resources help individuals to reduce potential strain, to proactively engage in a changing environment and to cope with potential stressors resulting from ongoing changes.

Resources can be divided into three clusters: (1) personal resources, such as competencies and characteristics of the individual, (2) organizational resources, e.g. task characteristics or work processes (routines) and (3) social resources, such as organizational or social support (UDRIS 2007).

As predicted and recommended by experts (e.g. LUCZAK et al. 2002), organizations, executives and employees will only be able to master the challenges of a rapidly changing world by adapting resource-oriented approaches. There are requirements to achieve high levels of innovation, performance and occupational health.

Based on such a resource-oriented approach SONNTAG et al. (2001) conducted a study with blue-collar workers (employees working in the maintenance department) in the automotive industry. Aim of this research was to investigate the impact of change processes on health, work safety and motivation (see Fig. 17.5).

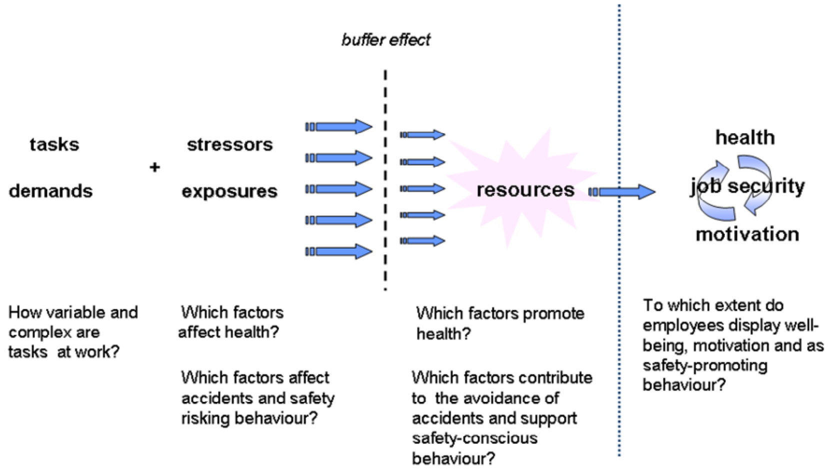

Fig. 17.5: Design for diagnostic of stressors, exposures and resources

Instead of asking illness-oriented questions (e.g. “Which factors can contribute to illness?”), employees were requested to answer health-oriented questions (e.g. “What keeps people healthy? How can potential negative consequences resulting from organizational changes be buffered by resources?”). Salutogenetic approaches (ANTONOVSKY 1987) or attempts at conservation of resources (see HOBFALL 1989, KARASAK 1979) job-demand control model focuse more on employees’ active coping with work demands and environment than on feelings of stress and accompanying consequences. In the field of work and organizational psychology there are well proved instruments and methods to analyse and describe stressors and resources (see EDELMANN 2002, GULMO 2008, ZAPF & SEMMER 2004).

3 Promotion of Resources

Human resources development activities like training and workplace learning maintain and promote executives' and employees' resources (see SONNTAG 2006, SONNTAG & STEGMAIER 2007). Diverse interventions are planned and implemented to help executives and employees to adjust and react effectively in this demanding context. In the following sections, selected interventions are presented (see SONNTAG & SPELLENBERG 2005). These interventions were part of the SERO-study, which aimed at motivating executives and employees to further develop personnel resources and to use them for effective coping with organizational change (see Fig. 17.6).

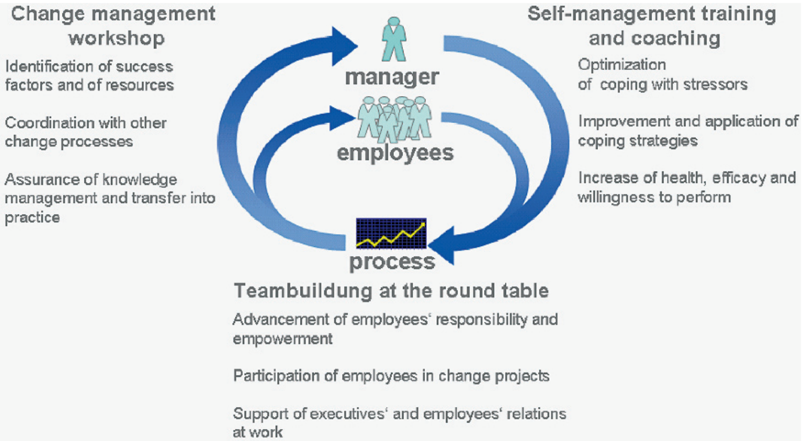

Fig. 17.6: Tools to improve communication and participation in change processes (SERO-study, SONNTAG & SPELLENBERG 2005)

3.1 Workshop to Plan, Implement and Evaluate/Reflect Organizational Changes

This workshop intended to help executives manage change projects by conducting fair decision processes (including preparing and if necessary revising decisions) and critical evaluation of one's own action. Besides instruments to evaluate change-specific leadership behaviour, executives were provided with tools for intended change projects. In particular, these tools and instruments could be used to analyse the following topics:

- Diagnosis of change environment
- Information and communication
- Participation and involvement
- Development of competence and support
- Evaluation and controlling.

Teams were composed of participants fulfilling different functions within the change projects, e.g. chief-executives, strategic managers, member of the change project and consultants.

3.2 Self-Management Training

Self-management trainings aim to provide participants with strategies to reduce work-related stressors, develop resources and reduce existing feelings of stress to improve their well-being. Trainings lasted for two days and executives were instructed in techniques to solve problems, to optimize time-management, to reduce stress and to relax in face of change-related work demands.

3.3 Teambuilding at the Round Table

Applying the "round table" method is one effective way to involve employees in the planning and implementation of change processes. It might be challenging however for executives and employees for the following reasons: Executives on the one hand have to learn how to elaborate their entrepreneurial objectives and to explain them easily to their team members. Employees on the other hand have to develop responsibilities for their own tasks and to emphasize their fields of competence. As a result, employees are often asked to optimize their self-management strategies.

4 Resources-Based Change Management

As described in the previous sections of this paper, resources are crucial for the successful implementation of organizational change. In the following section we conceptualize theoretical and practical implications of a resource-based change management (SONNTAG 2003) (see Fig. 17.7).

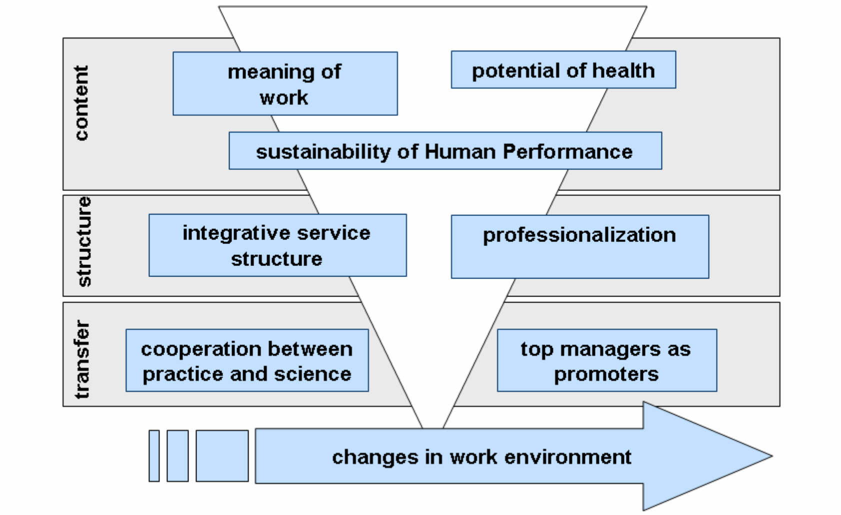

Fig. 17.7: Resource-based change management: theoretical and practical implications

4.1 Potential of Work and Health

Resource-oriented change management has to deal with a modern definition of work, which is characterized by new dimensions of structure, time and space (e.g. virtual teams or established home-offices). Fragmented working structures and "nomadic" changes in workplace locations will increase in the future. In response to rapidly changing work environments, resource-oriented change management has to adress answers to changed psychological sources of stress and strain. In this context definitions of illness as well as health have to be discussed. As defined by the World Health Organization (WHO), diseases are not only a physical dysfunction or damage, but also as a damage of identity or continuing negative emotions of fear and helplessness with disadvantageous consequences on thinking and acting. In contrast, health is defined as the capability to solve problems, to control emotions, to have a positive mental and physical state – especially a positive self-esteem – and to have a supporting network of social connections (BADURA 2000). According to these definitions "disease" and "health" can be regarded as medical and psychological categories, which are likely to have significant influence on employees' well-being and competence as well as organizational productivity.

4.2 Sustainability of Human Performance

Resource-oriented change management has to focus on both competence and health to sustain “Human Performance” in a changing occupational world. A theoretical and methodological approach of “competence development in working life” was developed by SONNTAG (2009). Based on innovative concepts and tools (e.g. taxonomy of competencies, workplace learning, continuous learning culture) professional competencies can be identified, shaped and improved to support sustainable human performance.

To address the objective of sustaining health in changing organizations, we focus on occupational health and safety prevention in one of our current research projects, which is supported by the Federal Ministry of Education and Research. The aim of this project is to demonstrate economic benefits of systematic occupational health management (as well as to point out further strengths and potential limitations). In addition, based on survey results, interventions to improve employees’ well-being and competence should be conceptualized, implemented and evaluated. These interventions should also be reflected in terms of their influence on economic key data. Objectives of this study are based on a well-elaborated model of resource-based health management (see SCHRAUB et al. 2008).

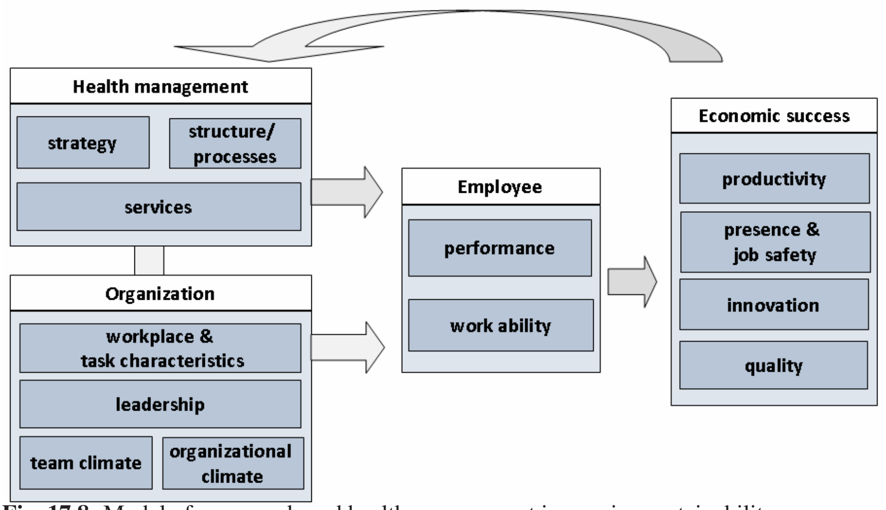

Fig. 17.8: Model of resource-based health management improving sustainability

This model illustrates factors, which are likely to have an impact on employees’ health (see Fig. 17.8). The following relations and effects are postulated in this model:

Positioning of the “health management department” in a company (reflected by strategy, structure, processes, offers and benefits), workplace characteristics (e.g. work structure, work load), leadership behaviour, team climate and organizational specifics are assumed to be positively related to economic success. Furthermore, it is supposed that both employees' performance and work ability mediate these positive relationships. In this model economic success is described in terms of productivity, status of employees' illness etc. Besides evaluating the theoretical model, part of this study is to evaluate the benchmarking position of organizations from different industries according to "health management".

4.3 Structure and Transfer

These topics, relating to the field of organizational change and occupational health, can only be attended if organizations (health and safety department and human resource management) develop and implement comprehensive resource-focused strategies and interventions. Potential stressors and resources have to be systematically analysed, demand-oriented interventions conceptualized and continuously evaluated and optimized. Interventions can focus on personal, work-related or structural aspects of the organization.

Implementation and transfer of resource-based change management strategies can be promoted by intense cooperation between science and industry. Organizations can help scientists to conduct innovative field research. Results of this research in turn can be used to optimize organizational change and occupational health management. Work and organizational psychologists are asked to point out benefits for organizations, which result from research on occupational health management (e.g. analyses of psychological stressors). Cooperating organizations have to realize the need of applied research. In addition, they have to understand, that possible study limitations (e.g. missing randomization, cross-sectional research, self-reported questionnaire data) may affect results' validity and generalization. Successful and long lasting-resource-based change management can only be implemented, if this is promoted by important stakeholders within organizations (e.g. top-management, works council). Top-management and executives have to set up conditions, which support planning, implementing and evaluation of organizational change and health projects.

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18 Designing Organizational Oblivion

Sebastiano Bagnara, Roberto Montanari, Simone Pozzi

1 Introduction

Organizations and humans forget. Both tend to lose previously acquired knowledge. Moreover, when forced to change, they have to learn how to discard competences and skills they already possess, even if they are distinctive components of their own identity. The learning process itself is often accomplished, for both organizations and humans, through a complex interaction between oblivion and knowledge creation.

This contribution will present the main theories behind the individual and organizational forgetfulness. Then, the major actions along which the organizations manage the oblivion are presented, by taking people, cognitive artifacts, communities of practice, and customers (as invaluable "mates" for the organization) into account.

It will be concluded that oblivion should be carefully designed in order to play a positive and active role during organizational change.

2 Individual Forgetting

Since the late 19th century, psychology has regarded forgetting as an unwanted, negative effect, as a loss, and provided different explanations for it, setting apart oblivion from traumatic amnesia or pathological degeneration.

One explanation, named "spontaneous decadence theory", assumes a temporal course of memories that fade together with their mnestic traces (HINTZMAN 1986), which, automatically and silently, fade through time. When experiences are not repeated or memories are not recalled, the remembrance of events will be lost. Reminiscences and experiences related to an emotional status leave stronger and deeper traces that last longer.

Another interpretation is known as the "interference theory" (BOWER & MANN 1992). It explains forgetfulness as caused by interferences between the knowledge

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that has still to be learnt and the knowledge that a person already possesses. This means that oblivion is not the result of a natural decadence of traces, but it is due to the interference between existing memories and novel experiences. According to this hypothesis, there are two different types of interference: retroactive or proactive. The retroactive interference comes into existence when newly collected information is detrimental to old memories, whereas the proactive interference allows possessed memories to interfere or modify the gaining of new knowledge. This explains why a remembrance rarely resembles an experienced event (BROWN & KULIK 1982) as well as the uncertainty and fallibility of eyewitnesses (LOFTUS 2003).

Another hypothesis considers oblivion as a "retrieval failure" (BADDELEY 1986), in which memories do not come spontaneously from our mind. Rather, if they subsist, they can be recalled if we come across clues in the environment where we live and in the activity we are actually running, which may activate what we keep in our mind. In this case, oblivion would be caused by the fact that clues to retrieve the already possessed knowledge are poor or lacking.

Alternatively, recent studies have conceived forgetting as not simply a memory loss, rather as an active process in the knowledge acquisition and learning. These studies take the moves from a paradoxical feature in human memory: sometimes, the act of remembering can cause forgetting (MACLEOD 1998). Indeed, CONWAY et al. (2000) have found detailed evidence of what has been called "retrieval – induced forgetting". In other words, the human beings seem capable of gaining knowledge that, in the meanwhile, leads to forget.

Recent findings have revealed that subjects who were told not to remember suffered from significantly more retrieval-induced forgetting than the ones who were not told to forget (STORM et al. 2005). Other studies (WAGNER et al. 2001), conducted within the same research framework, have even found the neural systems to be responsible for intentional oblivion, when applied in social context, or in the recognition of emotions through faces (STORM et al. 2005). It has also been shown how intentional forgetting could interfere in reasoning and in heuristic inference (SCHOOLER & HERTWIG 2004).

These findings suggest a more active role of oblivion in the memory processes, confirming the notion of what has been called, since the end of the Fifties, positive, intentional, motivated and, eventually, directed forgetting (JOSLYN & OAKES 2005).

In line with this perspective, other research, oriented towards the interaction between humans and artifacts in workplaces (PARLANGELI et al. 2003), have revealed that oblivion is an active process that avoids storing and retrieving information that, though useful and used for a short time, has become later obsolete. This is the case of operators in call centers who learn rather quickly to forget about all the information they use in a given outbound marketing campaign once it is over (BAGNARA & MARTI 2001).

These findings are quite interesting since they suggest the possibility that oblivion, and more precisely intentional forgetting, can be applied also to work activities. They allow putting forward the hypothesis that the active relationship between oblivion and knowledge does not concern only humans, but it might also influence organizations.

3 Organizational Forgetting

Since the early Nineties, a series of studies have been undertaken to determine whether and how organizations use and keep knowledge. Such studies demonstrated that almost all organizations learn. They have been also able to show that some organizations are better in learning, and that these organizations perform better. It has become commonly accepted that there are strong relationships between organization dynamics and knowledge (MARTIN DE HOLAN & PHILLIPS 2004). As a consequence, notions such as "learning organization" (WENGER 1998), "organizational memory" (BANNON & KUUTTI 1996), "and cognitive-based enterprise" (WILSON 1992) are nowadays quite familiar.

It was also shown that organizations are affected by forgetfulness: ENGESTRÖM et al. (1988) introduced this topic in a seminal paper, where they discussed the problems raised by the ways in which doctors forget, and provided a model for ethnographic studies of collective memory.

Indeed, organizations do forget. Forgetfulness affects organizations in two main ways. From one side, according to the well-known dichotomy advanced by NONAKA and TAKEUCHI (1995), it involves tacit knowledge, that, if not shared while practiced, cannot be reproduced, and remains stored in the mind of the person who possesses it. If that person leaves the organization, his/her knowledge is lost.

On the other side, organizations can be forced to forget by external changes. For instance, the transformation in the nature of work due to a globalization of markets and technological revolution (NATIONAL RESEARCH COUNCIL 1999) has led to a massive process of oblivion (BAGNARA 2005): many skill and competences have become obsolete, and new ones have had to be learned. As a consequence, explicit, declarative forms of knowledge are now prevailing, as they can be easily learned and transmitted.

Moreover, the knowledge within organization is often lost because it may be impossible to retrieve it when and where it is necessary (CONKLIN 1992), due to difficulties in the retrieving procedures. A relevant amount of research has been carried out recently in this specific domain, trying to set up effective strategies to find what gets lost, even if stored. The title of the William Jones's book "Keeping found what is found" represents an exemplar motto for this (JONES 2008).

More interestingly, BOWKER (1997) has also shown that the organizations learn to deliberately and strategically forget. Indeed, the knowledge acquired within an organization tends not to maintain its utility through time. It could become obsolete and lead to negative effects. On the contrary, organizational oblivion could have positive effects, by allowing the flow of new ideas and concepts (RIZZO et al. 2003). According to BOWKER (1997), organizations remove knowledge either by: (a) *clearance*, which means that an organization deliberately avoids and prevents that any information about a past event might be used in the present; (b) *erasure*, which means that an organization destroys any trace of the past in the present.

Other authors (MARTIN DE HOLAN & PHILLIPS 2004) categorize the organizations' deliberate oblivion along two dimensions. The first one has *accidental* and *incidental* oblivion as polarities, where the first is associated to the loss of valuable knowledge, and the second is related to the loss of inefficient knowledge. The second dimension has *established* and *new* knowledge as poles. The combination between such dimensions generates a matrix that identifies four modalities of organizational management in the oblivion: (1) *decadence*, which means the slow, automatic loss of knowledge as a result of not using it; (2) *catching failure*, which means the missed opportunity of storing in memory as a consequence of a lack of attention; (3) *active oblivion*, which means strategies to omit obsolete and non useful information by mean of erasure and clearance; (4) stop *of bad habits*, which means to avoid the chaotic development of new knowledge. The last region of the matrix (stop of bad habits) is acquiring a relevant role in the so-called brain-intensive and visionary companies (COLLINS & PORRAS 2002), which, stressed by competitiveness, lead to the proliferation of new ideas.

A different perspective about organizational oblivion is provided by the so-called *distributed cognition* theory, which states that knowledge lays not only in an individual's mind, but it is shared in a social environment (HUTCHINS 1995). According to this approach, knowledge and memories concern prevalently social facts and events rather than individuals' mental processes. This is especially true for events that occur in organizational contexts (ENGESTRÖM 2008). Each memory act is therefore spread off among the individual's minds and the external objects and social practices, that include the persons themselves, and other people which share the same scopes, i.e. the community of practice, the customers, the artifacts, and the tasks that the artifacts make possible.

An example of such a kind of dynamic distribution is described by HARGADON AND SUTTON (1997), when investigating the procedures through which the worldwide leading design company IDEO creates new concepts. Indeed, one of the keys to success for this organization resides in the strategic steering and continuous promoting of interactions among environments, people skills, easy access to tacit and explicit knowledge via ad-hoc artifacts (as the famous *tech-box*), and use of the prototypes already created as a deposit for future ideas (BUXTON 2007).

This latter approach suggests the cognition-related procedures in memories retrieving and knowledge acquisition cannot be restricted to the individual's inner mental process; rather they are distributed at least among the main components of socio-technical systems. This implies that the management of oblivion is feasible, intended as integrated actions on the various components of a system. The strategy and some of the actions of oblivion management will be outlined in the next paragraph.

4 Oblivion Design and Management

Oblivion, memories, and knowledge are spread into systems including the following four main components that interact together to shape a social-technical environment. These consist of: (1) people with their knowledge and skills; (2) the social community the people belong and refer to for the activity; (3) the physical, organizational, cognitive artefacts; (4) the customers, whose needs and desires represent the main scope of the working related activities.

In the following, actions oriented to promote an active and effective oblivion are briefly described per each of these components.

4.1 Actions Towards People

People, especially in knowledge, creative organizations (FLORIDA 2002), represent the "kern" of organizational memories. It goes without saying that they also play a crucial role in organizational forgetfulness. Indeed, when the existing knowledge and competences become obsolete, their update becomes essential to assure the organizations' survival. The process of updating is twofold: on one side it refers to the need to gain new knowledge. On the other, it implies that it becomes necessary to strategically operate so that people forget obsolete tasks and routines, which otherwise tend to prevail mostly in stressing conditions, and limit the workers' capability to adapt themselves to the new, different activities (COHEN & BACDAYAN 1994).

Two complementary ways are typically followed to push towards forgetting tacit skills: either dismissing people and/or turning obsolete procedures into automated, machine-conducted operations. Such combined actions were the common features of the huge restructuring process that took place in Europe during the Eighties (KIESELBACH et al. 2006).

Such actions could have both negative and proactive effects. The *negative* effects concern the potentially dramatic social disruption of communities that share, besides tacit knowledge about common activities (community of practice), social and ethical values and relationships. It can cause people the "corrosion of character" (SENNETT 1998). The *proactive* effects occur in the likely development, when the environment is favorable, of an industrial district (BRUSCO 1990). This outcome often takes place when employees have been forced to abandon a big company: they tend to create smaller companies, strongly linked each other, partly inheriting the "mother" company's business, partly finding new assets, skills, and competitiveness.

One approach, different from the forgetting imposed top-down, is the so-called participative change management (CIBORRA & LANZARA 1994). This approach insists on sharing, at all levels in a company, the objectives of change and focuses on the new framework and values, thus making people aware of what to learn and what to discard and forget. The oblivion becomes an intentional and shared tool for participating in a common endeavor.

4.2 Actions Towards Artefacts

People use tools and artifacts to perform their tasks. Any artifact, be it physical, cognitive, or organizational, embodies knowledge. When well designed (BAGNARA & SMITH 2006), they allow people to remember, immediately and intuitively, with no mental effort, which knowledge to use, which operation to perform, as well as how and when. In changes of production, in restructuring, in the current frenetic technological transformations (WINOGRAD 2008), the artifacts are continuously mutating. A new artifact might resemble an old one, thus reminding, and inducing old actions that turn out to be errors in the new context. Oblivion has become of crucial importance with respect to the use of artifacts, both at work and at home, in occupational life and in leisure time.

The full removal, the erasure from the artifacts, of any clue that might help one remember past, obsolete knowledge are formidable instruments for forgetting practices and skills, as well as learning new ones. However, designing artifacts that are easy to use, intuitive since they embody "affordances", but diverse from the previously experienced ones, is becoming rather difficult, often impossible.

Furthermore, attention should be put to the fact that artifacts are usually integrated, that is a physical or a cognitive artifact might be related with an organizational one. Then, an organizational clue might automatically recall actions related to obsolete cognitive artifacts. For this reason, the process of erasure should be integrated and integral. When this does not happen, people find in the field what might be still in the mind, and could enter a state of confusion and cognitive overload.

4.3 Actions Towards Communities of Practice

Communities of practice play a crucial role in keeping and improving skills, and knowledge. When new activities have to be performed, a social process of peripheral learning usually takes place: people in the periphery of the community, usually newcomers or previously marginalized members, find it easier to learn new knowledge, due to the lack of interference with the tacit knowledge characterizing the community itself. By doing so, they come to assume central roles. Vice versa, the persons, previously occupying the central positions, have to move toward periphery. Moreover, the tacit knowledge becomes obsolete, while the explicit one assumes the highest importance. The way and timing of transmission of knowledge changes: learning by imitation is no longer possible, partly because it takes too much time. The knowledge should be declarative and explicit.

These migrations within the community, the changes in responsibility, in the kind of the prevailing knowledge and in the way and timing of communication of it might give rise to conflicts, and even to the disruption of the communities. However, through the very same processes, that is, learning new activities and forgetting obsolete skills and tacit knowledge, the communities change and new communities are born.

Again, the complex social interaction between forgetting and learning has a twofold effect. That is why these social processes should be detected early, carefully monitored, and steered, by giving them incentives for the transformation along the objectives, and by providing educational support and training.

4.4 Actions Towards Customers

Customers are nowadays considered to be an essential component of the organizations themselves. This is most evident in the services sector or in design, marketing, and communication departments of even manufacturing sectors. Indeed, while performing her/his activity, each member of any of the organizations considers customers' satisfaction as the main reference and the measure of the quality of her/his performance.

On the other hand, the customers establish with the goods and services provided by an organization a kind of relationship that does not meet only physiological, utilitarian needs, but encounters emotions, feelings, desires, and wishes. The relationship is symbolic, social and cognitive, rather than material. Since this relationship is primarily emotionally based, it is quite stable and refractory to any change, though it appears to be very mutable. The customers are owners of a knowledge that organizations need to embody in the goods, and in shaping the services they provide.

It is hard (and even ethically questionable) to convince customers to change and to forget, following the transformations of organizations: the design of customers' forgetting is rather an impossible mission, though, in the latest years, sophisticated techniques have been developed in trying to silently persuade customers, and influence their behaviors (RUSHKOFF 1999). However, fortunately enough, besides ethical and legal issues, people tend to resist sharing with organizations their knowledge and even more their desires. It feels like an invasion of privacy, an assault to inner identity.

A less intrusive approach aimed at establishing a closer relationship with the customers has been developed since the seminal work of NORMAN AND DRAPER (1986). The "user centered design" has evolved by trying to embed into products and services not only users' cognitive requirements, but also tacit knowledge and different emotional statuses (NORMAN 2004).

However, customers seem to be unavailable to share and "sell off" their tacit knowledge, wishes and values, nor, fortunately, to be easily induced to forget them.

5 Design for Oblivion

It can be concluded that oblivion, far from being a pure passive process of loss, as many theories have maintained, plays a decisive, active role in shaping the knowledge of individuals and organizations.

Though forgetting processes may go unnoticed and are surely underestimated during relatively stable periods, they become of crucial importance in change and transformation times. Then, the forgetting processes have to be, sometimes, stimulated through ad hoc actions. In any case, they should be always managed by designing a consistent and unified strategy. Indeed, a clear and coherent oblivion strategy allows minimizing conflicts and the other negative effects that individuals' cognitive and emotional reactions, as well as social processes involved, can give rise to. It may also enhance the crucial role that forgetting plays in generating new and fresh ideas by favoring people and organizations to getting rid of the psychological and cognitive barriers characterizing obsolete thinking frameworks and scenarios. It might trigger the offering of a wide set of potentialities, that is a creative-proliferation strategy.

Of course these strategies should carefully choose among the various possible actions, which involve the main pillars of the organizations, namely: people, artifacts, communities, and customers. The actions have to be integrated and coherently deployed in order to reach the major objective by which an oblivion strategy can justify itself and therefore put into action: the survival and the harmonic development of an organization.

However, one should be well aware and keep in mind that a fundamental condition for the success of any forgetting strategy is definitely the wellbeing of the people, both those within the organization – i.e. the employees – and those, only apparently, outside of it – that is, primarily, the customers, but also the citizens at large. All in all, the oblivion strategies presented here are primarily aimed at contributing to reach this crucial, challenging scope.

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Part 3
Cooperation in Work Groups

19 Goal Setting: Basic Findings and New Developments at the Team Level

Jürgen Wegge, Klaus-Helmut Schmidt, Julia Hoch

1 Goal-Setting Theory: An Overview

The effects of goal setting on performance have been a major topic of psychological research. The most influential contribution to the field was made by Locke and Latham who developed the goal-setting theory (LOCKE & LATHAM 1990, 2006). According to Locke and Latham, goals are conscious intentions of a person referring to desired future end states of action. Goals can have their origin within the acting person or they can be set (more or less participatively) in discussions with other individuals (e.g., supervisors, colleagues). Independent of the origin of goals, goal-setting theory assumes that effects of goals on performance – once they are formed as an intention – mainly depend on two features: the objective *difficulty* of goals and their *specificity*. Two assumptions were postulated as basic research hypotheses:

(1) Striving for difficult goals should result in better performance than striving for easy goals (*goal difficulty effect*).

(2) Pursuing specific, difficult goals should result in higher performance than striving for vague, unspecific or no goals at all (*goal specificity effect*).

Today, more than 400 studies have tested these hypotheses (LOCKE & LATHAM 2006, LATHAM & LOCKE 2007). Apart from a few exceptions, it was found that both assumptions are valid. Thus, performance improves when individuals set themselves specific, difficult goals (compared to "I do my best" intentions). Providing the preconditions for this effect are favorable (e.g., moderate task complexity, high commitment, ability, cf. below), striving for challenging goals leads, on average, to an increase in individual performance of around 0.6 (±0.2) of a standard deviation (LOCKE & LATHAM 1990, 2006). In addition an impressive generalizability can be attributed to the observed effects. Goal setting has proved to be effective in field as well as lab settings, for many different kinds of tasks, and with persons of different age, gender, personality and cultural backgrounds.

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Based on these robust findings, goal-setting researchers have mainly analyzed two questions: The first question deals with identifying those *mechanisms* (mediator variables) causing the effects of goal setting and the second question concerns the influence of possible *moderating variables* of the goal-performance relationship. The major results of this research are summarized in Fig. 19.1 and will be elaborated in the following section. Next, we will discuss important new developments in goal-setting research that are related to goal setting in teams.

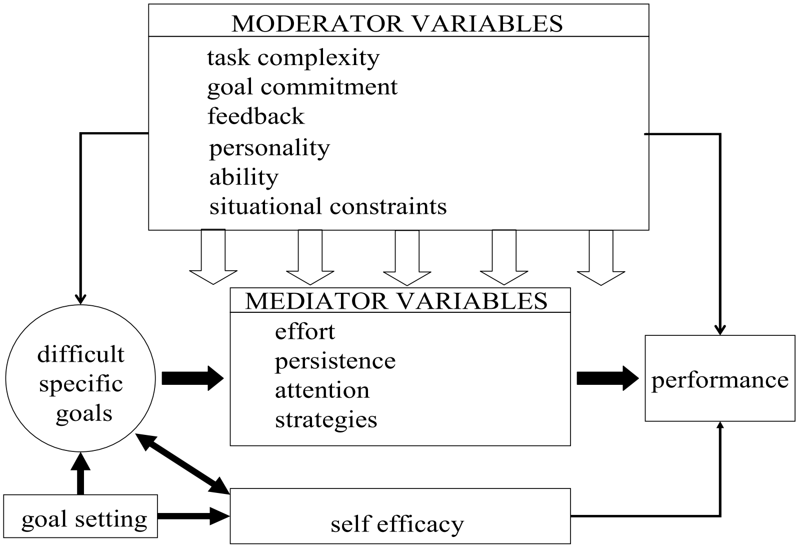

Fig. 19.1: Summary of findings in goal-setting research

1.1 Mediating Mechanisms: Why Does Goal Setting Work?

Many studies confirm that at least five mediating processes underpin the efficacy of goal setting (LOCKE & LATHAM 2002, WEGGE 2001). Goals influence performance by (1) concentrating and guiding attention toward task relevant information, (2) motivating people to invest more effort, (3) increasing persistence in goal pursuit, and by (4) developing and using appropriate task strategies (i.e., to engage in planning, see Locke, 2000). Finally, it was found that (5) self-efficacy and related processes (e.g., differences in emotion regulation that are not covered by the four other mechanisms) play a mediating role. Difficult goals set by an authority can directly increase self-confidence because such goals suggest that one deems the respective person to be capable of meeting them. Moreover, it was found that persons with high self-efficacy accept difficult goals more readily than persons with low self-efficacy (BROWN et al. 2005) so that effects of both variables are reciprocal. In line with this, variations in self efficacy (as indicators of stable personality differences) are also perceived as determinants of goal difficulty (see Fig. 19.1).

1.2 Moderating Variables: When Does Goal Setting Work?

Several moderator variables have been suggested and observed to contribute to goal-setting effects. Since performance improvements due to goal setting are about 8% for difficult tasks and about 16% for easy tasks (LOCKE & LATHAM 1990, p. 30), *task complexity* is an important moderator. There are several explanations for this moderating effect of task complexity (LOCKE 2000). In essence, though, it is assumed that on complex tasks the use of existing knowledge and the development (learning) of new appropriate strategies is most important for achieving good performance. In addition, solving complex tasks demands more time and more self-efficacy, and performance on these tasks is often also more contingent on an efficient decomposition of distal goals into proximal goals than performance on easy tasks. Therefore, in recent statements of goal-setting theory (LATHAM & LOCKE 2007, LOCKE & LATHAM 2006), it is suggested that for complex tasks goal-setting procedures should be adapted accordingly, for example, by formulating learning goals (e.g., “Find X new strategies to process tasks and test them”) and proximal goals instead of outcome goals. In addition, it is argued that goal setting on complex tasks should be accompanied by interventions that help people to meet the additional requirements of these tasks (e.g., interventions that facilitate and promote error management).

A second important moderating variable that has been intensively investigated in goal-setting research is *goal commitment*. If there is no goal commitment, the goal assignments of supervisors or others will have little or no impact. In support of this assumption, a meta-analysis of 83 studies conducted by KLEIN et al. (1999) found a moderately strong mean correlation between goal commitment and performance (r = .23). Moreover, for difficult goals the correlation is substantially higher (r = .35) than for easy goals (r = .18). Thus, commitment seems to be even more important for goals that are difficult to attain. As LOCKE and LATHAM (2002, p. 707) argue, this is because difficult goals require more effort and are also associated with lower chances of success than easy goals. Many variables have been investigated as potential determinants of goal commitment, in particular, financial incentives, expectations regarding goal attainment, the personality of followers, the power of supervisors, and leadership behavior (e.g., participation in goal setting; KLEIN et al. 1999).

In addition to task complexity and goal commitment, individually based goal-setting research has identified some other moderating variables, notably the *availability of feedback* during goal striving (such that having feedback during goal striving improves performance, in particular for complex tasks; e.g., NEUBERT 1998), the *personality of followers* (e.g., JUDGE & ILIES 2002 found that followers with high extraversion are most strongly motivated by goal setting), task-related *ability* (e.g., LOCKE & LATHAM 1990 observed that when ability is high, goal-setting effects are more pronounced) and *situational constraints* (e.g., when information or material necessary for task completion is missing, goals are not achieved).

2 New Developments in Goal-Setting Theory

LOCKE and LATHAM (2006) as well as LATHAM and LOCKE (2007) summarize several innovative developments in goal-setting research, e.g., a new focus on the effects of learning goals and proximal goals for complex tasks, the role of affect in goal setting, the role of goals as mediators of personality effects on performance, the ways in which priming affects the impact of a goal, and the extension of goal setting to the team and the organizational level. In the following, we focus on new findings related to group goal setting (goal setting at the team level) because, in our view, this development has relevance for many modern work settings.

2.1 Goal Setting for Teams: What do we Know and why do we Need to Extend the Theory?

LOCKE and LATHAM (1990) proposed that goal-setting theory is also valid for team work. Accordingly, teams should pursue difficult, specific team goals and it would be an important task for supervisors to encourage the formation of such team goals. However, research on goal setting for teams is relatively thin on the ground. To date, studies have tended to simply investigate whether the goal-setting main effect for individual performance – difficult goals yield higher performance than easy or vague "do your best"-goals – also emerges in situations where individuals work in groups. This is indeed the case, with results indicating that the performance of groups striving for a specific difficult group goal is almost one standard deviation higher (d = .92) than performance of groups that do not have challenging goals (O'LEARY-KELLY et al. 1994). This finding is based on 10 empirical studies. Since then, some new studies have analyzed the impact of group goals and these also confirm that goal setting works at the group level for different tasks (e.g., ANTONI 2005, DESHON et al. 2004, WEGGE 2004, WEGGE & HASLAM 2003, 2005).

Such findings appear to provide a robust basis for recommending the use of goal setting in teams. However, the mechanisms responsible for these effects have rarely been analyzed, as researchers tend to assume that the processes that mediate group goal-setting effect are *identical* to those that are responsible for goal-setting effects in individual performance situations (e.g., increased effort, see Fig. 19.1). At first view, this proposition would appear plausible since individual performance is obviously a critical ingredient of team performance. Moreover, in support of this idea, DESHON et al. (2004) found that group goal-setting effects were mediated by team effort. Nevertheless, there are several reasons for questioning the proposition that group and individual goal-setting effects are routinely identical.

First, the setting of group goals typically occurs in situations where groups of individuals perform complex tasks together. In itself, such a situation can arouse specific (social) emotions such as evaluation apprehension that might impair performance (WEGGE 2004) or specific expectations (e.g., regarding how individual performance and team performance are linked). For example, if team members expect that their individual inputs to the collective product will not be evaluated or are redundant, they often display social loafing (KARAU & WILLIAMS 1993). However, if they believe that their individual outcomes rely on the final team outcome and if they expect that other group members will perform poorly, then they may instead be willing to exert especially high levels of effort in order to compensate for weaker team members (social compensation) to ensure that the group succeeds (KARAU et al. 2000). In the same vein, group work typically involves additional processes such as communication and collaborative planning (WELDON & WEINGART 1993) or team feedback in addition to individual performance feedback (DESHON et al. 2004) that are not required or present in the case of individual performance. Moreover, as LOCKE and LATHAM (2006, p. 266) observe "groups add a layer of complexity because goal conflicts may occur among the group's members". Taken together, there is no doubt that additional variables (e.g., team planning, social loafing, team identification) come into play in team work and that variations in such team-specific processes can help account for variations in the efficacy of group goal setting. In the following, we summarize recent studies that extend our corresponding knowledge, also including modern forms of work, in particular, virtual team work.

2.2 Goal Setting for Teams: New Findings from Laboratory Research

In line with the arguments outlined above, WEGGE (2004) could demonstrate in a series of four experiments with ad hoc student teams that (a) group goal setting is effective (each experiment found a group goal-setting effect under specific conditions) and that (b) goal-setting theory has to be extended for team work. The main findings of these studies (using mediation analyses to reveal the causes of group goal effects) are as follows. Difficult, specific group goals can lead to better group performance because they:

- increase the subjective value of group failure
- encourage communication during processing team tasks
- foster intrinsic motivation in dealing with rather boring tasks
- prevent the use of inefficient task strategies.

These experiments further indicated that typical group goal-setting techniques increase collective self-confidence (potency) of team members, the value of group success, and the readiness for social compensation. Moreover, in particular, participative group goal setting yielded high group cohesion and team identification (WEGGE & HASLAM 2003, 2005). As there are some theoretical reasons to assume that participation is more important at the team level than at the individual level (e.g., the group context can strengthen the desire for voice and the possibility of resistance), a recent experiment (HASLAM et al. 2009) analyzed under which conditions participative group goals are more effective than assigned group goals. It was found that the benefits of participative group goals for brainstorming performance of teams relative to imposed goals becomes more marked as goals become more difficult over time. In sum, these results stress the theory's usability at the group level as well as the necessity of expanding it accordingly.

2.3 Goal Setting for Teams: New Findings from Field Studies (PPM)

Organizations use team work if a task is complex and comprises a multitude of different sub-goals (e.g., offering a timely, high quality, and cost effective service for different groups of customers) that can be achieved best by the joint cooperation of several individuals. However, even if performance for all different sub-goals (e.g., being on time, delivering high quality, wasting no material) are measured and fed back to a team continuously, team members confronted with this feedback face the problem of how they should distribute their available resources to achieve the different sub-goals and demands.

PRITCHARD et al. (1988) have proposed a new method of measuring group performance, the Productivity Measurement and Enhancement System (ProMES) that seeks to support group members in solving this distributional problem. Group participation together with a bottom-up approach and discussion until consensus is reached are the basic principles for the development of ProMES measures. Developing such a system implies three steps:

- determining the main objectives of the group that are in line with organizational goals,
- identifying performance indicators for each objective that are largely under the control of group members, and
- developing a contingency, a graphic utility function relating the amount of each indicator value to its productivity value for the organization, for each indicator (for details, see SCHMIDT & KLEINBECK 2006).

These contingencies inform group members about what their objectives are, what is expected from them in each performance area and how variations in group performance are evaluated by the organization. Inspecting these contingencies can thus help with the investment of resources into objectives and indicators where further improvements have greatest influence on overall group performance.

Once the measurement system is completed and approved by management, group members receive regular feedback on each performance indicator, which can be used for internal group goal-setting processes. Teams review their feedback, discuss how well they did (e.g., examining indicator measures that increased and those that decreased) and which new strategies might help them for doing their work better. ProMES has been shown to be a very effective intervention for improving group performance in a broad area of work settings. A recent meta-analysis of 83 field studies found large performance improvement effects following ProMES implementation with a mean unweighted effect size *d* of 1.16 and a weighted mean of 1.44 (see PRITCHARD et al. 2008). ProMES research can thus be seen as a good example of evidence-based management. Managers should use techniques and interventions (e.g., feedback, goal setting) that are based on firm empirical evidence of their success rather than on other factors (e.g., doing something because other organizations do it).

2.4 Goal Setting in Virtual Working Conditions

The impact of dyadic goal setting and team goal setting was recently also examined in virtual working conditions. Virtual working conditions (e.g., virtual teams) pertain to employees that work together from geographically and/or organizationally dispersed work sites, mainly via the usage of electronic communication media and information technologies.

WEGGE et al. (2007) examined the impact of goal setting on performance in two experimental studies (N = 126, N = 120) where telework in an advertising company was simulated. Participants, completing a brainstorming task via a PC video conference or face-to-face, were led by supervisors who utilized either directive, participative or "do your best" goal setting. Performance in either goal-setting condition was higher than in the "do your best" condition, particularly when working via video conference. Furthermore, in the virtual working setting, *participative* goal setting was more effective than directive goal setting. In other words, the strongest effects of goal setting under virtual working conditions were achieved when participative goal-setting techniques were utilized, probably because employees expect to have more voice in virtual working conditions and react most favorably if this is accepted by management. This result, however, may also be explained by the finding that participation typically increases goal commitment and self-efficacy, and thus compensates for potential effects of anonymity and de-individuation, which had previously been shown to reduce performance in virtual work settings (for review see, HERTEL et al. 2005). In line with this idea, KONRADT, HERTEL and SCHMOOK (2003), in a field study with 72 teleworkers, found that the quality of goal setting reduced stress and increased job satisfaction. Moreover, HERTEL et al. (2004) analyzed 31 virtual teams and showed that the most successful teams on average also had higher levels of goal setting. Thus, for virtual working conditions, participative goal setting and/or high quality goal-setting strategies in the sense of Hertel et al. seem to be a very promising leadership strategy.

Participative and collective team goal setting may also be realized via shared or collective leadership strategies within teams (PEARCE & CONGER 2003). Several studies have already shown that shared leadership improves team processes and team performance (PEARCE et al. 2008). Moreover, it can be assumed that this form of leadership is most valuable in virtual teams. As work is more distributed in virtual teams, shared leadership is needed to bridge the gaps between team members and to link together those who are geographically separate and in remote work settings. In support of this view, HOCH (2007), in a sample of 101 virtual and face-to-face teams, found that shared leadership led to a stronger performance increase in virtual teams than in face-to-face teams. Shared leadership also exceeded the impact of traditional supervisor (vertical) leadership (HOCH 2007). In another sample of 206 employees of virtual teams, shared leadership has been shown to increase performance via strengthening potency, social integration, and problem solving (e.g., PEARCE et al. 2004). In sum, it can be concluded that both traditional forms of dyadic participative goal setting and more modern, team-based forms of shared leadership are two important pathways toward success in virtual teams and virtual working conditions.

3 Conclusion

Modern industrial engineering has to take into account the various functions and robust effects of human goals for understanding and managing human work behavior. In this chapter we presented research results that support this basic view and also explain why and when goals determine performance. As different forms of group work become increasingly important in modern organizations, we further summarized the state of the art with respect to *group* goal setting. Our review shows that goal setting works at the team level, too. However, even if current research findings strongly corroborate the theory’s usability for teams, we should not overlook the necessity of expanding goal-setting theory accordingly. There is much work left for researchers, however, it is already obvious that additional mediating variables (e.g., team planning, team feedback) and moderating variables (e.g., face-to-face vs. virtual work conditions) come into play. In our view, two additional conclusions can already be drawn:

(1) The complexity of goals within team work requires the adoption of a formal management feedback system (e.g., we recommend ProMES) that helps to handle the multitude of potentially conflicting goals.

(2) Fair participation in goal setting pays off at the team level, in particular if teams continuously work together to achieve (increasingly) challenging goals and/or if team work is characterized by virtual working conditions.

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20 Simulation of Collaborative Product Development Processes Using Agent-Based Modeling

Xiaodong Zhang, Yu Yang

1 Introduction

Collaborative product design has been one of the most powerful and potential ways for companies to develop complex products in shorter development time. However, as the process is becoming more and more complex because of new forms of work and organization styles, the management of the development process becomes more and more challengeable.

Process modeling and simulation technologies are widely used to predict, analyze and evaluate the product development process (PDP). One important modeling and simulation approach is based on the design structure matrix (DSM), which was developed by Steward to model the information flow of design tasks and to identify their iterative loops. BROWNING and EPPINGER (2002) extended Steward's work and used DSM and advanced simulation techniques such as Latin Hypercube Sampling (LHS) and parallel discrete event simulation for PDP improvements and evaluating. Another important method is to use Petri Nets to model and simulate PDP by formulating task network. For example, YAN et al. (2003) used extended stochastic high-level evaluation Petri Nets (ESHLEP-N) to simulate the design process and therefore obtain a feasible product development plan. ZU (2005) developed a product development process model based on resources distribution and realized PDP simulation with a Colored Petri Nets simulation software.

Because the above models and simulation techniques are task-oriented, it is difficult for these approaches to describe and evaluate the influence of human and organization factors on PDP. In real product development projects, designers' behaviors and their organization style would impact PDP on a large scale. As a result, it is necessary for PDP modeling and simulation to consider human and organization performance. Organization-oriented modeling and simulation provides enabling toolkits for people to view, analyze, and try to understand a

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current organization through interactive simulation, model the changes to an organization as a result of design and policy changes, and ascertain in this synthetic environment what effects are likely to result from these changes (ZHANG et al. 2006, ZÜLCH 2006, LUCZAK & ZINK 2003, HAQUE et al. 2003, ROUSE & BOFF 2005). In this direction, LUCZAK and MUEHLFELDER (2003) analyzed the knowledge transfer process and task networks in computer supported cooperative work, and introduced a quantitative method for evaluating the effects of groupware usage on the emergence of shared mental action models (SMAM). HAQUE et al. (2000) analyzed the operation of multifunctional project teams throughout the new product development process lifecycle using process modeling and analysis techniques. BODNER and ROUSE (2007) used organizational simulation in an experiment to determine the product research and development value creation effectiveness of alternative investment policies. LICHT et al. (2004) developed a person-centered PDP simulation approach using Timed Stochastic Colored Petri Nets (TSCPN), in which qualification profiles and preferences can be assigned to persons dynamically, and persons can communicate with other involved persons.

However, it becomes very difficult to model human behavior as the complexity and uncertainty of the project increases. Complexity and uncertainty are largely due to the autonomy and adaptability of the designers during the process. To describe this characteristic of collaborative product development process, agent-based modeling (ABM) and simulation methods have been proposed in recent years. Agent-based modeling and simulation has proven to provide a valuable research tool for the analysis of large-scale complex systems. GARCIA (2005) mentioned the great application prospect of ABM in innovation and new product development research. YANG et al. (2007) used an agent-based modeling approach to simulate a product development process with some initial simulation experiments. LEVITT (2004) asserts that agent-based computational organizational modeling "comes of age" at the turn of the third millennium.

In this contribution, based on Yang's research (YANG et al. 2007), a detailed agent model structure and protocols are proposed to evaluate human and organization factors of product development process. Then, the approach is used in a real road design project based on the simulation platform D-PDP. Three human resource allocation schemes are evaluated, and the simulation results show the effectiveness of the approach as well as the accordance with the practical organization principles.

2 Integrated Simulation Model DTPRO

First, we present an integrated simulation model DTPRO (Designer-Task-Product Information-Resource-Organization, DTPRO), which can incorporate many general characteristics of collaborative product development processes. The model is constituted by designers' agent model, task network partial model, product information partial model, resource partial model and organization partial model. The integrated model has the following features:

- Modeling designers using intelligent agent with the structure INTERRAP, describing dynamic collaboration and iteration characteristics of designers' behavior by defining a set of behavior protocols.
- Modeling environment by taking tasks, product information, and resources as environment objects, and defining status and transition rules of these objects in their partial models.
- Simulating design process as a continuous interaction process of the design agents and the design environment objects, thereby describing complexity and uncertainty of the process in a natural manner.

Simulation process can be described as the collaborative solving process of the multi-agent in the design environment composed of tasks, product information and resources. The simulation principle can be expressed with the following formula:

$$\begin{Bmatrix} ST_0(\ ) \\ SP_0(\ ) \\ SR_0(\ ) \end{Bmatrix} \xrightarrow{\begin{Bmatrix} BD_0(D_1) \\ BD_0(D_2) \\ \vdots \\ BD_0(D_n) \end{Bmatrix}} \cdots \longrightarrow \begin{Bmatrix} ST_t(\ ) \\ SP_t(\ ) \\ SR_t(\ ) \end{Bmatrix} \xrightarrow{\begin{Bmatrix} BD_t(D_1) \\ BD_t(D_2) \\ \vdots \\ BD_t(D_n) \end{Bmatrix}} \cdots \longrightarrow \begin{Bmatrix} ST_T(\ ) \\ SP_T(\ ) \\ SR_T(\ ) \end{Bmatrix}$$

Here St={STt (), SPt (), SRt ()}, means status of the environment objects at time t, Di represents designer numbered i, n is the total number of the designers, BD() is the behaviors set of the designer. The formula above means that the behaviors of the designers at time (t-1) will change the environment status from St-1 to St, and then the designers perceive the new status of the environment and act new behaviors to the environment. The interaction will continue until the environment status fulfills the requirements of the product design at time T, namely, all tasks status are "finished" and all product information status are "known".

By adjusting agents' behavior protocol, status transition rules and organization relationships, human and organization impact factors of the collaborative design project can be evaluated through simulation.

3 Designer's Agent Model and Behavior Protocol

In order to construct a designer's agent model, the designer's behavior should be studied and abstracted first, and then the behavior should be illustrated with suitable intelligent agent structure. In a product development process, the designer's behavior can be divided into three kinds, i.e. reactive behavior, deliberate behavior and collaborative behavior. Since INTERRAP hybrid structure can illustrate multi-layers agent behavior, here we reference INTERRAP hybrid structure to model the designer's agent, as shown in Fig. 20.1.

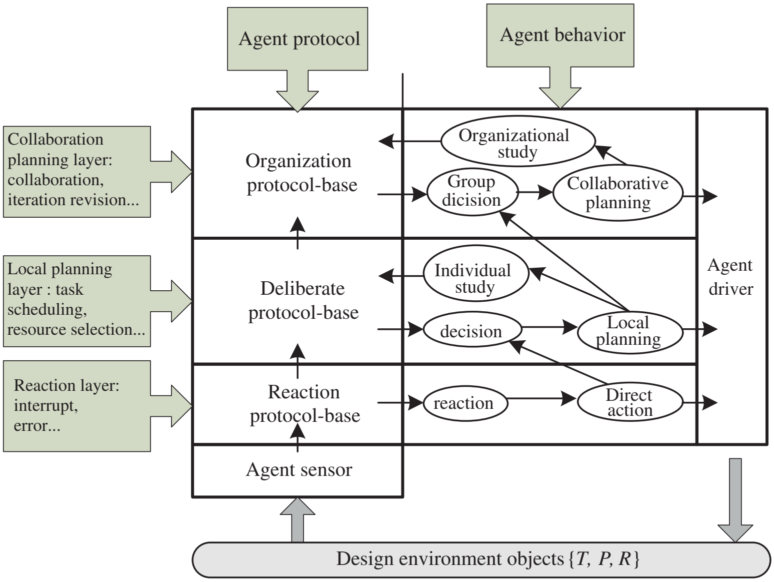

Fig. 20.1: Structure of the designer's agent model

Main components of the agent model include an agent sensor, agent protocol, agent behavior, and agent driver. The agent apperceives design environment objects, i.e. tasks, product information, and resource, by the agent sensor. Then, the agent behaves according to the status of the environment and his behavior protocols. Finally, the agent's action acts on the environment objects by the agent driver.

Agent behavior protocol can be defined as the decision process of the agent from environment status to agent behaviors, and can be expressed as: $S_t \times Protocol \rightarrow BD_t()$. As analyzed before, the agent protocol and behavior have a structure of three layers, i.e. reaction layer, local planning layer, and collaboration planning layer. When the environment information cannot be understood by one layer's protocol, it will be delivered to higher layer, until the information can be interpreted and the agent selects suitable behavior. The agent model also shows the human and organization learning process during his action. The behavior protocols are critical in deciding the task's sequence and the reliability of simulation results. Main protocols used in the agent model are listed below.

- Interrupt reaction (Reaction layer): React to the interrupt signal and stop current task immediately. Continue the task until recovery signal is received.
- Error reaction (Reaction layer): Redo the task from the start point immediately, and the repetitive work time will be shortened due to learning effect.

- Task scheduling (Local layer): Decide executive priority of the tasks assigned.
- Resource selection (Local layer): Decide what resources are suitable to be utilized.
- Partner selection (Collaboration layer): Decide collaborating partner who is suitable to cooperate with.
- Collaboration (Collaboration layer): Micro-activities of the two agents during interaction. Collaboration happens frequently among designers in collaborative product development process, which can be divided into online and offline collaboration. In online collaboration, one designer cooperates with another designer to finish the collaborative work together. While in offline collaboration, one designer sends collaboration request to another designer, and then waits for the results from his collaboration partner.
- Exception report (Collaboration layer): Report exception to his superior and wait for the instruction. Act differently according to the serious extent of the exception.
- Iteration rework (Collaboration layer): Redo a finished task because there is feedback information from one downstream task to upstream task.
- Design revision (Collaboration layer): Redo a finished task because the input information of the task has been changed by upstream task.

4 Simulation Case Study

Based on DTPRO model and above protocols, a simulation platform named Designer-oriented Product Development Process Simulation (D-PDPS) is developed using Visual C++ programming language. D-PDPS has the agent-based programming structure and realized integrated visual modeling and simulation process of PDP. Some initial experiments were conducted using the simulation platform. The purpose of these experiments is to compare the influence of different organization task assignment on the project time, designer's efficiency and occupation rate.

Figure 20.2 is one of the integrated simulation models we built as elementary experiment. There is a total of 7 team members in this design team, one is the team leader, and the other six are engineers. In the model, *TA* means task, *PI* means product information, and different kinds of arrows mean information flow, task allocation, and organization relationship respectively. The seven members will act according to protocols defined in the agent model.

Main simulation inputs parameters are listed in Table 20.1. In this research, we use task normal time *NT* to represent task workload, which is defined as the time that a normal designer uses to finish a regular design task with the normal speed at the normal technology conditions. *NT* is the most important input of the simulation. It can be estimated according to task attributes, be studied by time study, or be rated by design experts according to historic data. In this experiment, *NT* is rated by design experts. In order to check if the task is finished in simulation, we define another time parameter, i.e. task effective work time (*WT)*, which means the designer's effective work time on one task during simulation. "Effective" means that *WT* does not include additional task time which is used for waiting collaboration or report feedback. When *WT* is equal to *NT* during the simulation, it means that the designer's current workload has achieved pre-defined workload. At this time, the agent will stop this task and mark the status of the task to be "finished". The third term about time is total time *TT*, which means the total time the designer used for the task. The value of *TT* is the sum of *WT* and additional waiting time used for collaboration and report.

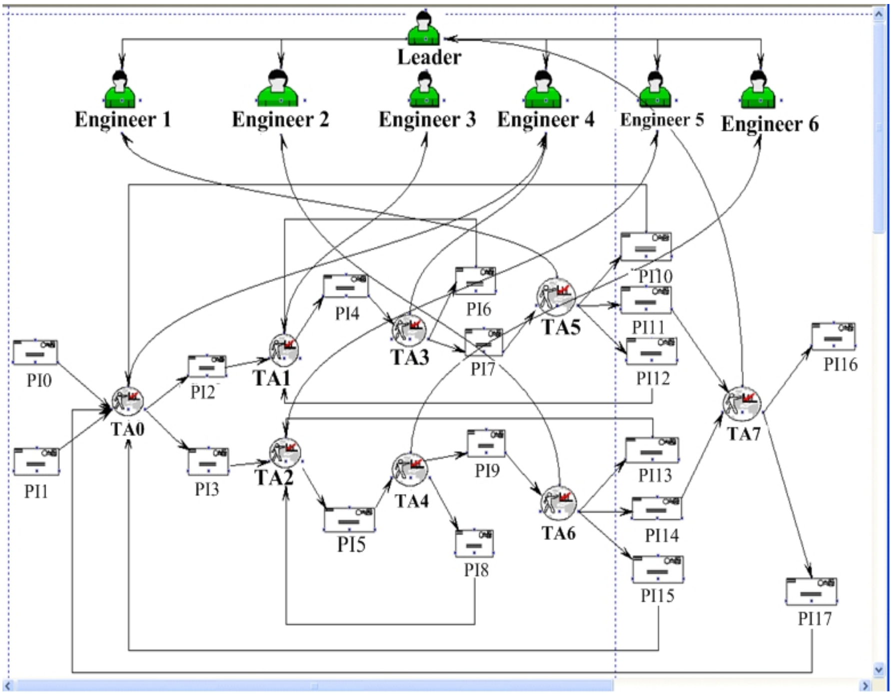

Fig. 20.2: Integrated model of the 7-member-team experiment

There are in total 18 product information items as tasks input and output in the experiment. At the beginning of the simulation, only the status of PI_0, PI_1 are “known”, the status of other items are all “unknown”. As the simulation runs, the tasks are finished one by one and the status of product information will be changed from “unknown” to “known” correspondingly. The whole simulation will stop when the status of all product information are “known”, which means all designers have finished their tasks.

In the DTPRO model, learning factors of designers are considered when the designer has to redo his task. This will happen when the designer fails to do the task, meets an exception, or his upstream tasks are revised and he has to rework. In these cases, the work time will decrease because the designer has done the task before. The parameters of learning factors for fail, exception, and rework can be worked out by studying learning curves of relative design work.

Work fail, collaboration, and exception will occur during the simulation. We adopt probability to reflect these situations. The probability for fail, collaboration and exception are represented by α, β, γ, which can be rated by design experts or be statistically analyzed by work sampling method.

Table 20.1: Main input parameters of the simulation experiment

Input Parameter	Value
Original tasks *TA*	TA_0: CAD concept design;, TA_1: CAD design of part 1; TA_2: CAD design of part 2; TA_3: CAE analysis of part 1; TA_4: CAE analysis of part 2; TA_5: CAM programming of part 1; TA_6: CAM programming of part 2; TA_7: Examination
Normal time *NT*	NT_0=3 、NT_1=5、NT_2=3、NT_3=4、NT_4=5、NT_5=4、NT_6=3、NT_7=3
Initial status of Product information item *SP()*	*SP_0=Known, SP_1= Known* *SP_j= Unknown* (j=2,3…17)
Learning factors of designers	Fail_decrease =0.7 Except_decrease=0.5 Rework_decrease =0.8
Fail_prob:*α*, collab_prob:*β*, except_prob:*γ*	*α*=5%， *β*=4%， *γ*=3%

Based on the model of Fig. 20.2, we try to make the organization “lean” by cutting out Engineer 2 from the 7-member-team. Therefore, TA6, which is performed formerly by Engineer 2, is now assigned to Engineer 1 and the other parts of the simulation model keep same as the original state. Furthermore, a 5-member-team is formed by cutting Engineer 3 out from the 6-member-team. Engineer 3’s task

TA1 is done by Engineer 6. Comparative simulation study will be conducted based on the three schemes.

Figure 20.3 shows the work process and accumulated work time of the agent Engineer 4 from the 5-member-team along the timeline during one simulation run. In this simulation run, the simulation duration for all members to finish all tasks is 32 time units. TA8 is a temporary task added to Engineer 4 due to collaboration request from Engineer 5. Then Engineer 4 has to stop TA3 to deal with TA8 and Engineer 5 have to wait when Engineer 4 dealing with his request. From the simulation process, the autonomy behavior and organization collaboration of the designers are described visually and naturally.

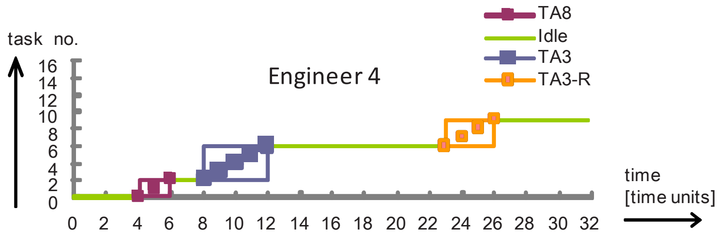

Fig. 20.3: Work process of each designer

To identify differences among the schemes, hypothesis tests are used. All hypotheses are tested with the help of t-statistics-test for independent samples (α=0.05). The project total time (*PTT*) of 7-member-team is 25.44 days and the *PTT* of 5-member-team is 29.74 days. The *t* value of *t*-statistics for independent exceeds the critical value 1.65, and means the value of *PTT* for 7-member-team is significantly shorter than *PPT* for 5-member-team by 14.45%. However, the average *PTT* value of 6-member-team of 100 simulation runs is 27.34 days. The t-test shows that it has no obvious difference with the *PTT* of 7-member-team. That means that the 6-member-team can finish the project on time even when the organization has one less team member. However, the 6-member-team requires Engineer 1 to be competent for TA6, namely, requires Engineer 1 to have higher qualification. This result is well consistent with practical organization principles: With higher qualification team member (or multi-skilled member), the design organization might be leaner. Based on such analysis, the project manager can optimize his human resource utilization at the planning stage of the project.

5 Conclusion

Product development process simulation is a powerful approach for process prediction, management, evaluation, and improvement. However, it is difficult for task-oriented simulation approaches to reflect the autonomous and organization characteristics of the designers in collaborative product development process. The simulation modeling approach in this paper uses an intelligent agent model to reflect the essence of the complexity and uncertainty of the collaborative work process. Three organization schemes with the given collaborative product development process are designed for case study. The simulation result shows that this approach provides a quantitative and flexible method to study and improve human and organization factors in collaborative product development process.

This simulation approach based on agent model depends largely upon the integrity and reliability of the behavior protocol. Therefore, future work will focus on the validation and extension of the behavior protocols, as well as practical evaluation indices of human and organization factors aiming at the collaborative characteristics of the process.

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21 Integrated Modeling of Work Processes and Decisions in Chemical Engineering Design

Wolfgang Marquardt, Manfred Theißen

1 Introduction

In all engineering disciplines, design processes are a fundamental and frequent task. They serve to elaborate an *artifact description that satisfies a given functional specification* (MOSTOW 1985). In chemical engineering, these artifacts are chemical products, the associated production plants including the process and control equipment, and operation and management support systems (MARQUARDT & NAGL 2004). The artifacts are described by documents such as process flow diagrams, equipment lists, and construction plans.

While the modeling of the *work processes* in chemical engineering design has gained increasing acceptance in the past, and while there are at least suitable approaches for modeling the *decisions* taken during design projects, there is no adequate support for the *integrated* modeling of these two aspects. In this contribution, we present a *decision process ontology* integrating the procedural aspect and the rationale. The ontology permits representing *concrete* design projects for documentation purposes; such documentations can serve as the foundation for supportive functions in a design tool, including semantic search for documents, change tracking (e.g., to determine the effects of modified requirements on an artifact), and others. The outstanding characteristic of the ontology is its expressiveness for *decision process templates*, i.e., generalized descriptions of design processes meant to *guide and support* designers working on a concrete problem.

In Sect. 2, we give a brief review of existing modeling approaches for design processes and design rationale. In Sects. 3 and 4, the two constituent ontologies of the decision process ontology – a process ontology and a decision ontology – are presented. Section 5 deals with their integration to form the overall ontology. In Sect. 6, the practical application of the ontology is discussed.

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2 Approaches to Design Process Modeling

2.1 The Procedural Aspect of Design

The procedural aspect of design covers the different steps or *actions* of a design process, the *information* and *documents* required for and created during their execution, the *actors* involved, etc. Such procedures or *work processes* can be described on different *levels of generality*.

The lowest level of generality refers to a *concrete case*, i.e., the documentation of a specific design project. Such a documentation can help to track the course of a project, to record interdependencies between the documents created, to search documents in the context of the work process, etc. For instance, the Process Data Warehouse (BRANDT et al. 2008), allows to capture and store concrete work processes, but also metadata about their products (i.e., documents), and provides powerful retrieval functionality based on semantic technologies.

More general representations of work processes do not refer to a single design project, but to a class of more or less similar design processes. Such work process templates help to establish a common understanding and terminology across organizational and disciplinary boundaries, they can serve as guidelines for designers, and they are required for implementing software tools for design process support (EGGERSMANN et al. 2002). Examples of work process templates in chemical engineering include the process design procedure by DOUGLAS (1988) and, more recently, PAS 1059, a procedural model and terminology for plant design published in 2006.

The *level of detail* indicates the amount of information captured in a model. On a low level of detail, only some top-level actions corresponding to project phases would be mentioned, whereas a more detailed representation would also give subphases or even the actions of individual designers. In case of a concrete project, in principle each of the actions performed could be refined and decomposed in an iterative way in order to reach an arbitrary level of detail. For templates, this is not possible. For instance, in order to decompose a "Design reaction unit" action in a general template for chemical process design, a plethora of possible subordinate actions like "Select reactor type", "Survey literature", and "Calculate reactor dimensions" would have to be given. However, the conditions to decide which subordinate actions should be performed in a particular situation are too complex to be represented by means of the standard elements of work process models. In general, design processes are creative, non-deterministic, and weakly structured, i.e., it is not possible to give detailed descriptions of all actions *a priori* (EGGERSMANN et al. 2008). Therefore, work process templates for chemical process design are often restricted to the enumeration of some project phases.

A pivotal obstacle to more detailed templates is the lack of modeling languages for weakly structured work processes; conventional techniques like the activity diagrams of the *Unified Modeling Language* (UML 2005), the *Business Process*

Modeling Language (BPMN 2002), or *Event Driven Process Chains* (EPC, SCHEER 2000) are tailored to well-defined or even deterministic work processes like software or business processes. In CRC 476 IMPROVE, a joint research project involving experts from engineering, computer science, and industrial ergonomics (NAGL & MARQUARDT 2008), the *C3 notation* for weakly structured work processes has been developed based on UML activity diagrams (EGGERSMANN et al. 2008). Several case studies have proven that C3 is an adequate language for the participative modeling of complex industrial design and development processes (THEIßEN et al. 2008a). However, C3 has never been intended to serve as a means for representing the rationale of design processes.

2.2 The Rationale of Design Processes

Design rationale is *reasoning that goes into the design of an artifact* (DUTOIT et al. 2006). It covers the evolving cognition of a design problem gained during a design project, including the requirements the artifact must fulfill, the different design alternatives that have been considered, and the disclosure of arguments for and against the alternatives. Like work processes, design rationale can be represented on different levels of generality. The rationale of a concrete design project is on the lowest level of generality. More general rationale templates apply to classes of design problems such as the design of polymerization processes or chemical processes in general.

Several notations and models for design rationale have been proposed. *IBIS* (Issue Based Information Systems) by KUNZ and RITTEL (1970) is probably the best-known. IBIS models consist of *issue* elements representing a problem or task to be solved. *Ideas* describe possible solutions for an issue. In addition, the *arguments* for or against different ideas are captured in an IBIS model. The simplicity of IBIS models is intended by its authors; the notation has been designed for capturing ongoing discussions about so-called *wicked problems* in social policy (RITTEL & WEBBER 1973). Wicked problems cannot be dealt with by linear solution procedures because a full understanding of the problem cannot be gained before elaborating an adequate solution.

IBIS has been modified and extended by several authors. For instance, in *QOC* (Questions, Options, and Criteria; MACLEAN et al. 1996) the criteria to be fulfilled by a suitable option (roughly equivalent to an idea in IBIS) are represented explicitly. *DRL* (Decision Representation Language; LEE 1990) is even more expressive: *claims*, i.e., statements which may be judged or evaluated, can be linked to represent complex argumentations in a straightforward manner.

In principle, these approaches are intended for and tailored to represent the design rationale in *concrete* projects. As for *templates*, HORDIJK and WIERINGA (2006) propose a generalization of QOC called *Rationale Building Blocks* (RBB). An RBB describes a generic design problem in conjunction with its available solution options and their effects. When applying an RBB to a concrete problem, the designer must evaluate the options in the context of the problem on hand.

2.3 Integrating the Procedural Aspect and the Rationale of Design

Both the procedures and the rationale of design projects in chemical engineering can be represented *separately* by the notations and models described above; *integrating* these two aspects into a single model allows a more comprehensive representation of design projects, and consequently it permits a better support for designers.

For instance, BURGE and BROWN (2002) argue that the Unified Process (a complex process template for software design; JACOBSON et al. 1999) should be annotated with information about the underlying rationale in order to allow software developers to tailor the Unified Process to their needs. More specifically, NEIGER and CHURILOV (2004) propose to enrich the functions in an EPC with the objectives to be reached by the functions. (A *function* in EPC terminology corresponds to a step or *action* in a work process model.) This allows the execution of an EPC to be guided by the specific objectives in a concrete case.

A prominent example in the field of chemical engineering is *KBDS*, a *Knowledge Based Design System* for chemical engineering by BAÑARES-ALCÁNTARA and LABABIDI (1995). In an extended version called *KBDS-IBIS* the process model of KBDS has been integrated with IBIS (BAÑARES-ALCÁNTARA & KING 1996). This tool offers supportive functions like automatic report generation and backtracking the effects of changes in design specifications. In a similar way, the modeling environment *ModKit* makes use of IBIS for the documentation of decisions during the creation of mathematical models (BOGUSCH et al. 2001).

Hence, integrated decision process models for *concrete* design projects do exist and have been implemented at least in prototypical tools. These models cover the main issues related to both the procedural aspect (i.e., actions, information items, actors, ...) and the rationale (i.e., alternatives, arguments, ...). In contrast, models for decision process *templates* typically suffer from a low expressivity for rationale. The decision process ontology presented in the following sections provides the same expressiveness for both concrete cases and generalized templates. This is a prerequisite to overcome the limitations of the existing, process-centered modeling approaches for design templates in chemical engineering.

3 An Ontology for Work Processes

As mentioned above, the decision process ontology integrates an ontology for work processes and an ontology for design decisions. We first describe the former of the two constituent ontologies.

As C3 has proven to be an adequate notation for representing design processes, the process ontology is based on this notation. A complete description of the ontology can be found in EGGERSMANN et al. (2008); its main classes and relations are given in the upper part of Fig. 21.1. These elements are the building blocks for modeling both concrete work processes and work process templates on the instance layer. For some classes and relations, the graphical depiction of their instances in a C3 model is shown. Note that in this contribution, the term *graphical* depiction or representation refers to a visualization of a model to be used and interpreted by human beings, not to the more abstract concept of a graph in mathematics and computer science. In particular, a model can exist independently from a visualization.

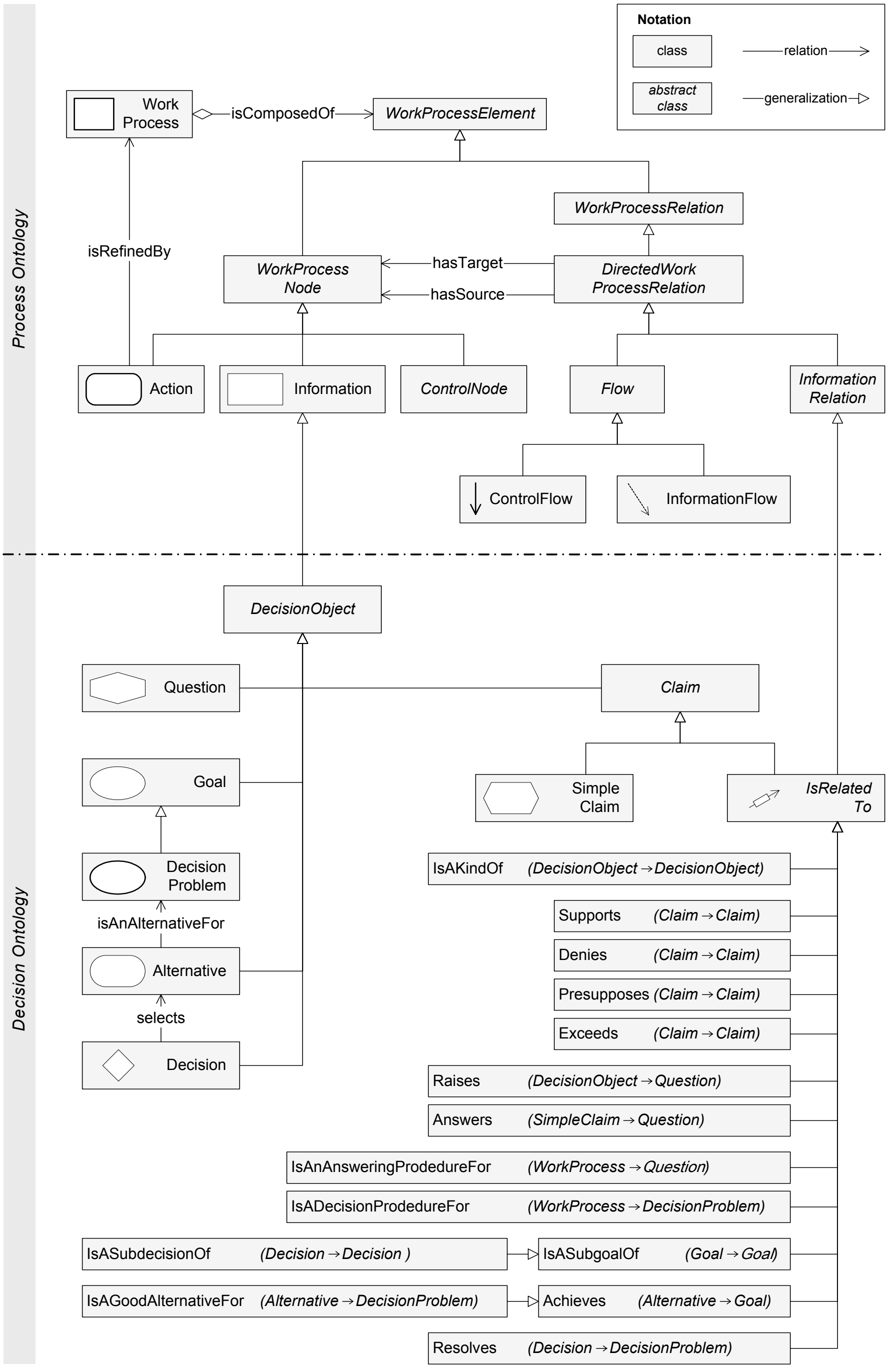

Fig. 21.1: An integrated ontology for work processes and decisions

A *WorkProcess is Composed Of Work Process Elements,* which form a network consisting of *Work Process Nodes* and *Work Process Relations*. *Work Process Nodes* comprise *Action* and *Information* elements. (An *Action* corresponds to an *Activity* in C3. The term *Activity* had been adopted from the terminology of the activity diagrams in UML 1.x. In the ontology, we have renamed *Activity* to *Action* in compliance with the terminology of UML 2.x.) In addition, there are *Control Nodes* such as *Fork Nodes*, which indicate the beginning of two or more control flows in parallel (the subclasses of *Control Node* are not given in the figure). Via the *isRefinedBy* relation, an *Action* can be linked to a subordinate *WorkProcess* which provides a more detailed representation of the *Action* on a finer level of granularity.

Most *Work Process Relations* are binary *Directed Work Process Relations* characterized by a source node and a target node (relations *hasSource* and *hasTarget*). In a graphical depiction of a work process on the instance level in C3 notation, a *Directed Work Process Relation* is represented by an arrow from its source to its target; examples of *Directed Work Process Relations* include the *Control Flow* between *Actions* and/or *Control Nodes* and the *Information Flow* between *Actions* and *Information* elements. The *Information Relation* is a relation between two Information elements. The *Synchronization* of two or more Actions (not shown in the figure) is an example of a *Work Process Relation* which is not directed.

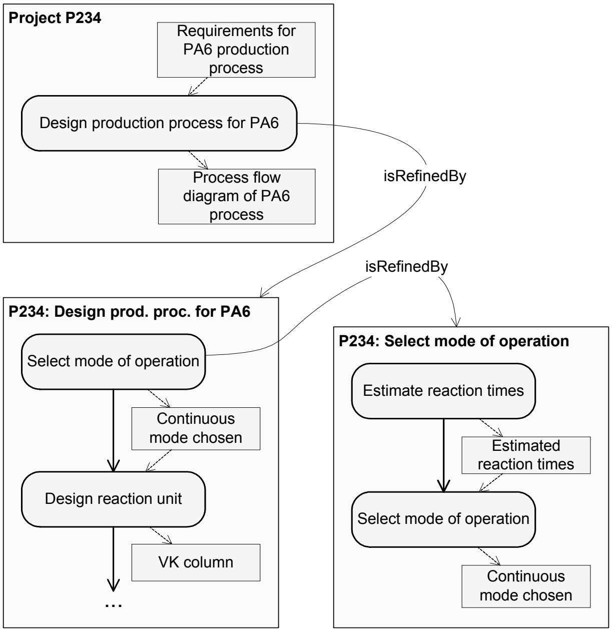

Fig. 21.2: A simplistic model of a concrete design process

To illustrate the use of the process ontology, a simplistic model of a concrete design process for PA6 (polyamide6, a thermoplastic polymer) is shown in Fig. 21.2. On top, the overall *WorkProcess* “Project P234” is shown, which contains a single *Action* “Design production process for PA6” as well as two *Information* items: The “requirements” the chemical process must fulfill are the input of the design *Action*, whereas the “process flow diagram” is its output. The design *Action* itself *isRefinedBy* a more detailed *WorkProcess* called “Design production process for PA6”, containing further *Actions* like “Select mode of operation”, which generates the output *Information* “Continuous mode chosen”, and “Design reaction unit”, which is based on the chosen mode of operation. For the first *Action*, an even more detailed *WorkProcess* is shown, which indicates that some characteristic reaction times had been estimated before the mode of operation was chosen.

Obviously, restricting the representation of a design process to the procedural aspect suffers from several deficiencies. The requirements for the chemical process are hidden within a simple *Information* element, although they are decisive for the progress of the design process. Also, no information is provided about the arguments that have let the designers choose a continuous mode of operation. In particular, it is unclear why the reaction times were estimated before deciding on the mode of operation.

4 An Ontology for Design Decisions

The Decision Representation Language (DRL) by LEE (1990) is an expressive, but nevertheless intuitive graphical notation for such design rationale. Its ability for representing complex argumentations was decisive for choosing DRL as the foundation for the decision ontology described in this section.

As shown in the lower part of Fig. 21.1, all classes of the ontology are derived from the abstract *Decision Object*. Instances of the five classes given in the left part of the figure, including the *Simple Claim*, form the nodes of a decision model. A *DecisionProblem* is a design problem that requires a *Decision*; the relation *IsASubdecisionOf* permits to decompose a *Decision*. *Alternatives* are the options meant to solve a *DecisionProblem*. The desired properties of *Alternatives* are represented by *Goals*, which can be decomposed by means of *IsASubGoalOf*. Two further relations, *Achieves* and *IsAGoodAlternativeFor*, are used to evaluate an *Alternative* with respect to a *Goal* or a *DecisionProblem*, respectively. *Questions* are issues to be considered in the context of a *DecisionProblem*. Finally, a *Decision* represents the selection of one *Alternative*, i.e., it *Resolves* a certain *DecisionProblem*.

Any statement in a decision model which may be subject to uncertainty or to discord is represented by a *Claim*. *Claims* are either *SimpleClaims* or relation classes derived from the abstract *IsRelatedTo*. In fact, most of the relations between the elements introduced above are derived from *IsRelatedTo*, i.e., they are *Claims*. For the sake of clarity, the ranges of *hasSource* and *hasTarget* for these relation classes are given in textual form in Fig. 21.1. For example, in case of *Resolves*, the range of *hasSource* is *Decision* and the range of *hasTarget* is *DecisionProblem*. The graphical representation of *Resolves* on the instance layer is an arrow labeled “Resolves” from a *Decision* instance to a *DecisionProblem* instance.

Four additional relation classes derived from *IsRelatedTo* (*Supports*, *Denies*, *Presupposes*, and *Exceeds*) permit to represent complex argumentations. *Denies*, in particular, can be used to negate any *Claim*.

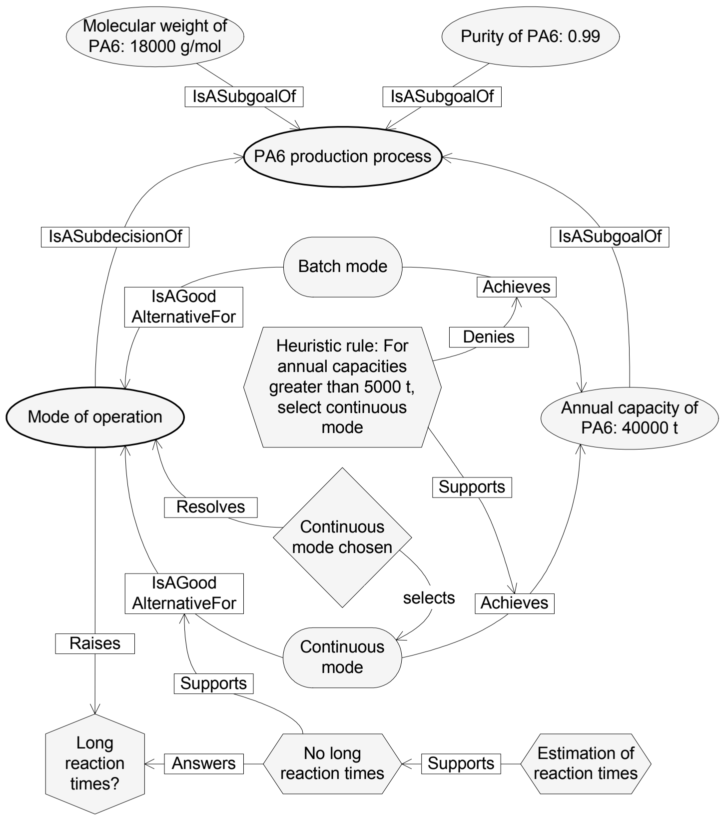

Fig. 21.3: Exemplary model of some design decisions in a concrete project

Figure 21.3 shows part of the rationale in the concrete design project discussed above. The overall *DecisionProblem* is to specify a “PA6 production process” in conformance with *Goals* like a certain “Annual capacity”, “Molecular weight”, and “Purity”. Selecting a “Mode of Operation” *IsASubdecisionOf* of the overall problem. Two *Alternatives* (“Batch” and “Continuous mode”) are given for the “Mode of Operation”. A heuristic rule, modeled as a *SimpleClaim*, *Denies* that the “Batch mode” *Achieves* the capacity *Goal*, and it *Supports* that the “Continuous Mode” *Achieves* this *Goal*. In addition, it is stated that the “Mode of operation” *Raises* the *Question* whether “Long reaction times” occur. An “Estimation of reaction times” *Supports* that there are “No long reaction times”. This *Claim*, in turn, *Supports* that the “Continuous mode” *IsAGoodAlternativeFor* the “Mode of operation”. Finally, the *Decision* to *Select* the “Continous mode” *Resolves* the *DecisionProblem* to choose a “Mode of Operation”.

Thus, the decision ontology permits to represent the information missing in the procedural model in Fig. 21.3: The *Goals* are explicitly modeled, the Alternatives are given with their pro and counter arguments, and it is stated that the estimation of reaction times is required for answering a *Question* relevant for choosing an adequate mode of operation.

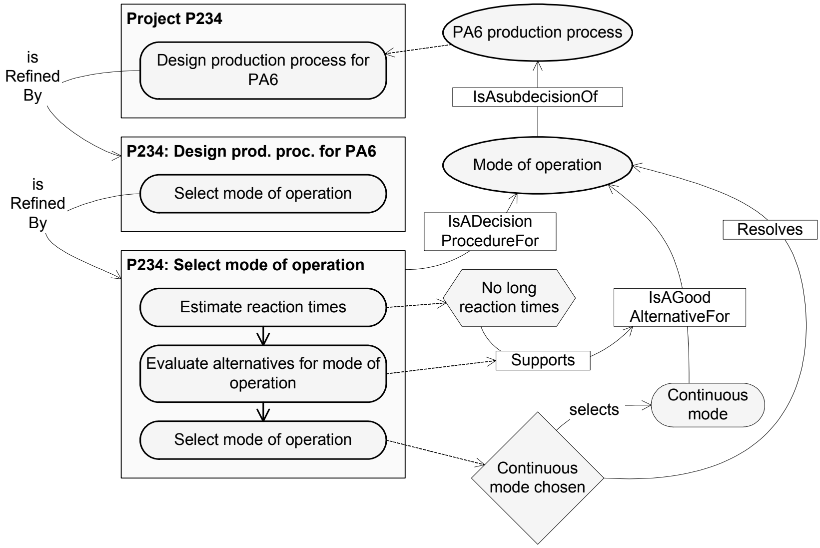

Fig. 21.4: Simple decision process model of a concrete design project

5 An Integrated Ontology for Work Processes and Decisions

The integration of the two ontologies for work processes and decisions to get an overall ontology for decision processes is based on two principles: First, the *rationale* a decision is based on as well as all the elements of this rationale are considered to be products of the *Actions* in a design process. In Fig. 21.1, this is indicated by deriving the *DecisionObject* from the *Information* class in the process ontology. Second, it is assumed that certain sub-processes or process chunks are *triggered* by the necessity to answer certain *Questions* or to decide about certain *DecisionProblems*. To this end, the relations *IsAnAnsweringProcedureFor* and *IsADecisionProcedureFor* have been added; these relations link a *WorkProcess* to the *Question* or *DecisionProblem* it is meant so solve.

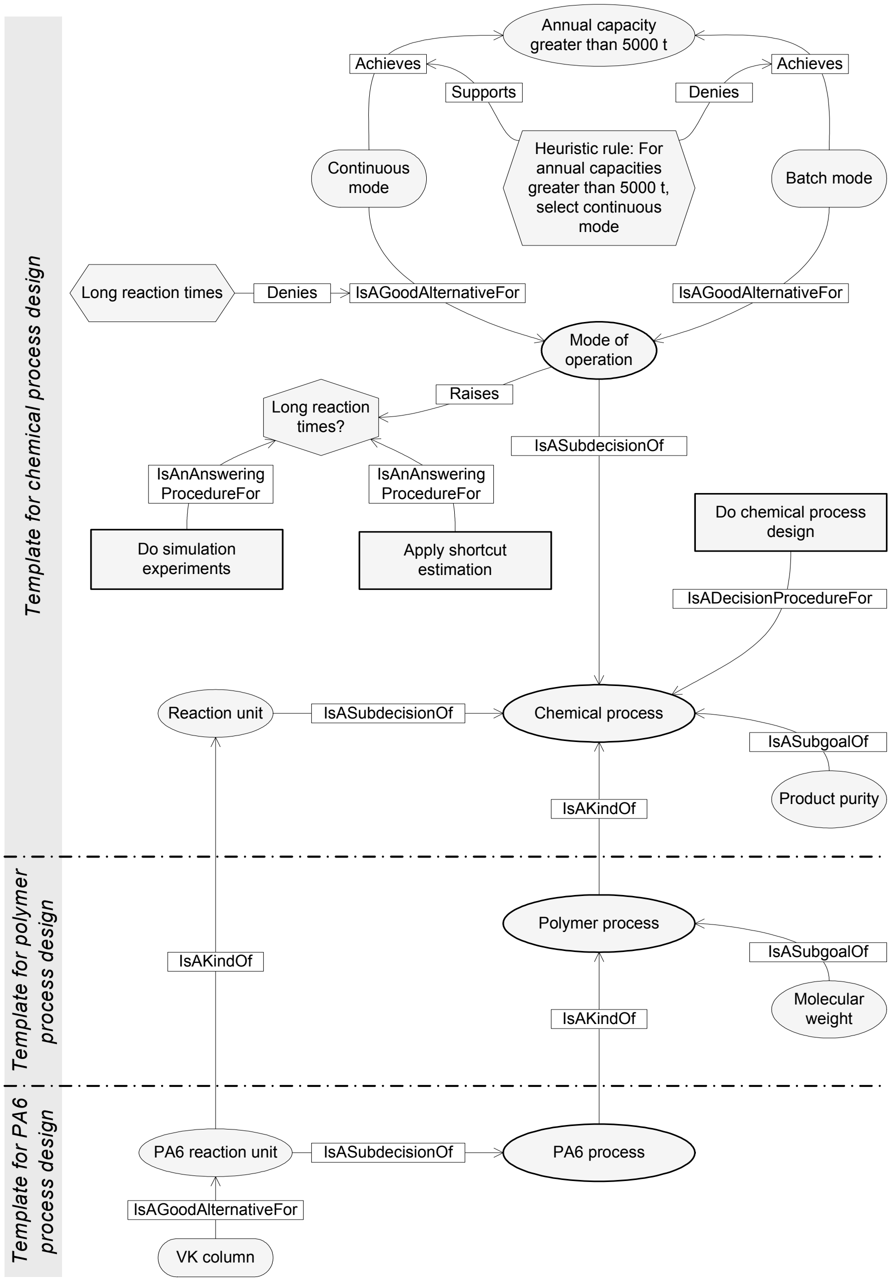

Fig. 21.5: Decision process templates on different levels of generality

Figure 21.4 shows how to combine the concrete process and decision models discussed above to get a concrete decision process model. Note that not all elements of the decision model are shown to keep the model readable. The *DecisionProblem* "PA6 production process" is an input *Information* of the top-level "Design production process" *Action*. Within the "Select mode of operation" *WorkProcess*, the *Action* "Estimate reaction times" has produced the *Claim* "No long reaction times". A subsequent "Evaluate" *Action* has led to the conclusion that this *Claim Supports* that the "Continuous mode" *IsAGoodAlternativeFor*" the Mode of operation". The final *Action* has produced the *Decision* to *select* the "Continous mode."

The example models presented so far deal with a concrete project. However, the ontology can also be used to represent generalized *templates* of decision processes. Templates are meant to support concrete decision processes. A designer applying a template has to decide which parts of it are relevant for the concrete problem he is working on. To this end, three attributes (*Applicability*, *Weight*, and *Evaluation*) are declared for *Claims* (for details on these attributes, see THEIßEN & MARQUARDT 2008).

Figure 21.5 shows three templates on different levels of generality. On top, the *DecisionProblem* to design a "ChemicalProcess" is given, including typical sub goals like "Product purity" and sub decisions like "Reaction unit" and "Mode of Operation". For the latter, two Alternatives ("Continuous" and "Batch mode") are shown. A heuristic *Supports* that a "Continous mode" *Achieves* the *Goal* of an "Annual capacity greater than 5000 t", and it *Denies* that a "Batch mode" *Achieves* this *Goal*. For both the *DecisionProblem* "Chemical Process" and the *Question* "Long reaction times?" *Raised* by the "Mode of operation" sub problem, *WorkProcesses* with procedural instructions are given via *IsADecisionProcedureFor* and *IsAnAnsweringProcedureFor*. For instance, the *WorkProcess* "Do chemical process design" would state that a *Decision* for the "Mode of operation" should be made before working on the "Reaction unit" problem.

The *DecisionProblem* representing the design of a "PolymerProcess" *IsAKindOf* the "ChemicalProcess" problem. It inherits all information in the more general template, and it contains a further subordinate *Goal* "Molecular weight", which would not be adequate for a chemical process in general. Finally, an even more special "PA6 process" *DecisionProblem* is given. It states that in the context of a production process for PA6, a "VK column" is an *Alternative* to be considered for the "Reaction unit".

6 Using the Integrated Ontology

A detailed discussion of the usage of the decision process ontology is given by THEIßEN and MARQUARDT (2007). First of all, *concrete* decision process models help to improve the communication between different stakeholders on the status of a design project. To this end, team members add *Goals*, *Alternatives*, *Claims*, etc. to a common model of the decision process. Explicit representations of the design rationale are also useful in later phases in the lifecycle of a chemical plant. For instance, assume that a damaged reactor in a plant must be replaced. Due to technical progress and changes in the market since the design and construction of the plant, there may be better alternatives than the installation of a reactor of the same type. However, normally only a technical specification of the old reactor is available at best, but there is no description of its requirements which would be necessary for the selection of a better reactor.

In contrast to models of concrete decision processes, *templates* are a means to support designers working on a new problem of a certain kind. Templates provide information about *Alternatives* that may be useful in a certain context, they give arguments for and against the *Alternatives* depending on the context, and they refer to subordinate *WorkProcesses* which could be executed to solve the overall *DecisionProblem*. Thus, the decision process ontology is a major improvement compared with traditional, process-centered representations of templates for chemical engineering design.

The main obstacle to the industrial usage of explicit representations of design rationale is the overhead for their creation. Templates are a means to *reduce such effort* as they contain at least part of the rationale relevant for a concrete case. Vice versa, as detailed by THEIßEN and MARQUARDT (2007), templates can be created based on the information contained in concrete models.

Obviously, the application of the decision process ontology requires *substantial tool support*. The ontology is implemented in *OWL* (Web Ontology Language; OWL 2004), a formal language for knowledge representation. Currently, a modeling tool is built that will be able to import the class definitions in the ontology and provide an intuitive user interface for the creation of models on the instance layer (THEIßEN et al. 2008b). In particular, the complexity of the models is an important issue. Even the simple examples in this contribution reveal that realistic models are likely to become unmanageable due to the number of the elements contained. Therefore, the modeling tool must support different views on the model, which focus on some aspects, but omit others.

7 Conclusion

We have presented an ontology for representing both concrete decision processes and generalized decision process templates in chemical engineering. Its outstanding characteristic is the integration of the procedural and the rationale aspect of design processes. The ontology permits to build both comprehensive models of concrete design projects and meaningful templates for classes of design problems. A final evaluation of the approach in industrial settings is in progress (THEIßEN et al. 2008b).

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22 Serious Gaming: The Impact of Pervasive Gaming in Business and Engineering

Matthias Jarke, Markus Klann, Wolfgang Prinz

1 The Computer Game Debate

Similar to television overuse a couple of decades ago, overuse of interactive computer games is causing a lot of public debate. Spectacular cases like a highschool student who killed several people after seven hours of violent computer games cause politicians to demand stringent regulations about so-called "killer games", or even full control over Internet usage by young people.

The scientific evidence in this area is slowly mounting even though there are obviously no simplistic single-factor explanations. From earlier research in the TV sector, it is known that a small, but significant share of about 10% of the potential for violence can be explained by regular TV watching (two hours per day, leading to about 10.000 violent scenes per year). Knowing that 15% of students spend more than six hours per week with violent games and 2.5% even more than 20 hours per week, and that these games are much more captivating than passive TV watching, one could hypothesize a much higher potential for "real" violence generated from such games. Initial results of fMRI analyses of brain activities demonstrate that violent video computer games stimulate the same brain regions as real physical danger and aggression (WEBER et al. 2006, MATHIAK & WEBER 2006). Together with the old observation, that gaming is one of the most effective ways of learning, one could indeed be concerned.

Internet-based gaming environments such as Second Life or World of Warcraft capture the attention not only of millions of players, but also of educators and business planners. The attractiveness of gaming appears to facilitate the handling of technical information, increases visual attention, concentration, and motivation on the topic of the game, and can assist academic knowledge acquisition as well as certain aspects of social competence. Especially the Second Life environment where human users are represented by avatars in a virtual graphics-based world, has been used as a site of "real" businesses, as a window for distance education, and as a playground for numerous social scientists testing e.g. gender effects and

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the like. However, Second Life is also an example of the short lifespan of game settings. By the end of 2008, the majority of the millions of registered users have stopped activities, presumably to move on to the next generation of game settings. One of these directions is called Pervasive Gaming in which the game leaves the purely virtual world and re-enters the physical world (BENFORD et al. 2005).

Starting from the visionary talk by MIT Researcher Tom Malone at the very first International Conference on Computer-Human Interaction over 25 years ago (MALONE 1982), researchers have asked how experiences from computer games can influence the design of IT-intensive systems, and how the games themselves can be used as a basis for design. Under the label of "serious gaming", a conference series in the US (www.seriousgames.org) has started in 2002 to discuss applications of computer gaming in, e.g., the military, education and training, public administration and corporate strategy planning, the health and cultural heritage sector, and last not least in marketing. Some initial attempts in this direction have also been pursued in production planning in Germany, exploring e.g. game-based extensions to business process modeling and simulation.

In this chapter, we present some research results concerning the further development in two directions: firstly, the evolution of present virtual game technologies towards "pervasive" games in which the players become – so to speak – their own avatars, and the playground moves into an augmented real world. Secondly, the systematic usage of gaming in early requirements engineering for new software-intensive engineering technologies, exemplified in our case by wearable computing technology for firefighters.

2 Pervasive Gaming

Successful game design is often characterized by a good game "flow" of continuous engagement and decision-making with immediate feedback and continuous challenges, e.g. through multiple game levels. In the typical "sawtooth" temporal organization, a slow build-up of tension is followed by a rapid release which is then again followed by a new build-up etc. In addition, the intensity to which tension is built, should also be varied over time.

Pervasive Games are a new form of computer games that aim at moving the game play out of the computer into the real environment. This new trend is motivated by two major facts:

- Innovations in video and computer games focus on improving the computer graphics to become more realistic, while the forms or genres of computer games are stagnating.
- The miniaturisation of technology combined with the availability of new sensors enables the development and use of new mobile devices for the game play beyond the traditional computer desktop.

Several approaches exist for the definition of pervasive games. Table 22.1 provides a comparison between classic computer games and pervasive games to illustrate the differences and advances.

Table 22.1: Classic vs. pervasive computer games

Classic desktop based computer game	Pervasive Game
Computer desktop is the primary game location.	No limitation to a computer desktop. The player's position controls the game play.
Game environment is a virtual environment inside the computer.	Real Environment becomes the game environment.
Player controls an avatar representing the player inside the game.	Player himself becomes the game character.
Player is (mainly) playing alone.	Mainly cooperative game play.
Game played for a fixed time interval.	Game played over a longer time period and interwoven with other activities.
Player controls the game by a special game device (gamepad).	Real objects and players become elements of the game.
Interaction with others is performed through the computer.	Direct interaction between the players.
Game is focused on a computer based medium.	Integration of natural media.

To illustrate this new form of computer games, the following subsections present some examples of pervasive games that implement features listed in the table. We start with Geocaching, a simple but widespread community-based game to illustrate that pervasive games are already in daily use. Then we present two pervasive games developed at Fraunhofer FIT with more advanced technologies.

2.1 Geocaching

Geocaching[1] is a form of hide and seek game that was enabled by the availability of consumer GPS devices in combination with a web-based community. The idea

[1] http://www.geocaching.com/

of the game is that people hide small treasures at interesting places. This hide is called a geocache. The geographical position of a cache is then published at a community site in combination with a homepage for each cache that contains additional information about the location.

People (i.e. the geocachers) who want to seek a cache, download the coordinates into their GPS device and then they start looking for the cache, navigated by the GPS device. Once they have found the cache they can log their success in the logbook at the cache homepage.

This basic principle has been extended by a number of game elements. Many cache locations are not provided by absolute values, but must be identified by solving a quest that is described at the cache homepage. Other caches can only be found by solving several location-related quests to retrieve the final cache coordinates. Such a multi-cache is often combined with a crime or adventure story and a touristic and educational background. Furthermore the users have invented a so-called travel-bug, which is an item that is carried by geocachers from one cache to another. Often a travel-bug is associated with a goal such as going to Hawaii and back, to collect as many city-caches as possible, or to win a race of two travel-bugs to a certain location.

This description of some of the geocaching concepts illustrate how a community has adopted location-based technologies to develop a simple kind of pervasive game that adopts several of the principles identified above.

2.2 Epidemic Menace

Epidemic Menace (LINDT et al. 2007) is a more complex pervasive game that aims at the integration and combination of different media and interaction technologies. Baseline of the game is a crime story about researchers who experiment with dangerous viruses and who released these viruses into the environment. After watching an introductory video the players are organised in two teams of four players. Goal of each team is to capture as many viruses as possible.

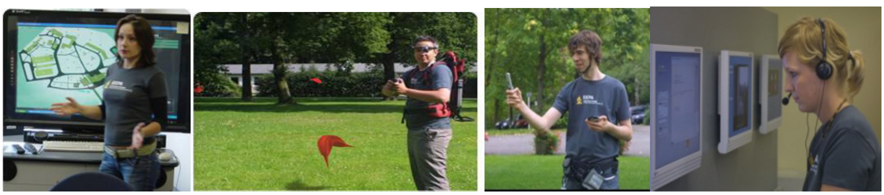

Fig. 22.1: Players using different interaction devices in Epidemic Menace

The game is played in a predefined environment such as a park or campus. Each team is equipped with (Fig. 22.1):

- a team room.
- a large interactive display that shows the location of the viruses as well as the location of the players on the playing field.
- a GPS-based tracking device that tracks the players while they are on the playing field.
- a smart phone that displays a section of the playing field map as well as the viruses. The smart phone is also used to capture viruses if the user is close enough.
- a head mounted display that presents viruses in the field of view while the user is walking around the playing field. Using a special spray device this user can also capture viruses if he is close enough.
- communication devices that enable voice communication between players in the field and in the team room.

The teams have to play this game in a cooperative way by splitting up into a group that remains in the team room, and players who enter the playing field to capture viruses. The team room players have the best overview of the playing field as well as virus and player positions, including the players of the competing team. This enables them to direct the own team players to those positions where they can find most viruses. The actual wind and weather and conditions are used by the game engine to drift the viruses over the playing field. This can become dangerous for the players as their health and playing abilities are reduced when they come to close to a virus without capturing it.

Epidemic Menace game events have been organised twice at Fraunhofer Birlinghoven Castle to evaluate the game design as well as the use of the different interaction devices. These game events have indicated that players are able to quickly understand the game design as well as the interaction devices. Players liked the cooperative nature of the game as well as the ability to manipulate the game by running around in person, instead of navigating an avatar through a game pad. Perhaps the most important fact indicating the success of such is that the players stated that they forgot about the time and that they got into a flow.

2.3 Time Warp

The experiences with Epidemic Menace led to the development of a pervasive game that is no longer restricted to a closed campus, but uses a whole city as the playing field. TimeWarp[2] (BRAUN et al. 2008, BROLL et al. 2008, HERBST et al. 2007) represents an interactive mixed reality game that combines historical quests with the exploration of the city of Cologne. Players are equipped with a mobile

[2] The development of Epidemic Menace and TimeWarp is partly funded by the European Commission as part of the Integrated Projects iPerG and IPCity.

device that tracks the position of the players. At certain city locations the mobile device provides a quest to the user. Quests involve the use of a head mounted display to adopt and change the real environment and architecture to a historical scene. The user can experience how buildings looked like in the medieval age, including sounds from that period. Characters appear to ask questions related to that scene (Fig. 22.2). After the user has successfully solved a quest he is guided to the next location.

The goal of the game is to travel through different time periods (current, Medieval, and Roman) of Cologne to save the "Heinzelmännchen" (prominent dwarfs of a Cologne legend) from being kidnapped by aliens. While playing the game the user will learn about the locations and history of a city; thus the game can be compared with an educational and entertaining city tour.

Fig. 22.2: A dwarf at a fountain in Cologne asking a quest about the city arms

2.4 Discussion

This brief overview illustrates three generations of pervasive game development. Geocaching involves only simple technology (GPS device) to augment the real environment with virtual paths and landmarks. Epidemic Menace uses a multitude of technologies but still requires a dedicated area to be equipped with Wireless LAN and communication media as well as a team of game managers to orchestrate the game at a dedicated and temporally limited game event. The commercial success of the Nintendo Wii – even though still more limited in its local context – indicates that this is a promising direction for future game research and development.

In contrast, TimeWarp requires no local installations and can be played individually without the backup of game managers. Again, the success of mobile pervasive games with somewhat less sophistication in their virtual and augmented reality components – e.g. the RExplorer mobile cityguide with contextualized advice in Regensburg (www.rex-regensburg.de) – indicates the potential of this kind of game. Common to all pervasive games is the use of a natural environment, interaction and sensing devices to move game play beyond the computer desktop.

3 Serious Gaming

The term "serious gaming" – made popular through the US-based Serious Gaming Initiative since 2002 (www.seriousgames.org, now part of the annual Games Developer Convention) – describes computer or media games or game-based concepts whose main purpose is not just entertainment. Such use of gaming has a long tradition especially in the military but also in business games. Nevertheless, the convergence of high-performance simulation with fast and increasingly mobile communication technologies and rich media provides a new quality. The most recent trend, pervasive gaming, enables gaming beyond the traditional desktop interface and uses the natural environment as playground. An early example in the educational sector is the exploration of a city under different historical perspectives, as supported in the TimeWarp game.

While in the US the main application domain for serious gaming remains military simulation and training, the application domains studied in Europe are broader. Examples include education and training, cooperative simulation of processes in business and public administration, marketing, the health sector (www.gamesforhealth.org), and emergency management which has been our main research focus.

3.1 Serious Gaming in Engineering Design

Defining the requirements for breakthrough novel technologies has historically proven extremely difficult, because people from the relevant application domains have great difficulties to envision the consequences of these technologies for their own life and work environment.

A traditional way to address this issue for individual devices and simple software applications has been rapid prototyping by which the future users can get some impression what their future will look like and what consequences their requirements decisions might have for them. For complex natural science or engineering phenomena, such as automotive crash tests or material and energy flows in complex process industry settings, high-performance simulations combined with visualizations by videos or even virtual reality have become feasible and popular in the last years (JARKE et al. 1998, SUTCLIFFE et al. 2005). Moreover, traceability mechanisms have been designed to document the relationships of these media artifacts with the related design decisions and conceptual objects (RAMESH & JARKE 2001, JARKE et al. 2004).

However, when we are no longer talking about local and centrally controlled effects, but are considering complex social environments, gaming becomes an interesting extension to scenario-based design decision support. Future users and other stakeholders can explore the impact of new technologies, specific requirements, and particular design decisions, taking advantage of the immersive properties and high learning rate typical for well-designed games. Pervasive gaming appears as a particularly strong candidate, because it allows you to use a mixture of already existing real equipment and prototypes in a real setting, while being able to augment this reality with envisioned additional components that do not exist yet, and with artificial activities and events from different use or misuse case scenarios. Similar to e.g. crash simulation analysis, another advantage is that this can be done at significantly reduced cost and physical danger to participants, compared to a full-scale physical prototype environment.

Unfortunately, a good design of pervasive games is not an easy task. Many projects in this area have failed after spending hundred thousands of Euros, most often because game flow, fun and immersion were not accomplished. In an innovative engineering design environment, the additional problem arises that there is initially a very large number of widely different possible future technologies and contexts to be considered, which further hinders the development of high-quality pervasive games at acceptable cost.

In order to get around this hurdle in highly complex socio-technical innovation design settings, we propose a *staged game-based design approach* which develops and exploits a series of increasingly realistic games in order to explore requirements and design solutions in an intertwined manner. In the sequel, we describe some experiences in the European wearIT@work project on future uses of wearable computing in work scenarios, focusing on the specific work scenario of firefighting in large-scale emergencies (KLANN 2007).

3.2 The FireSim Case Study

One of four main work scenarios in the wearIT@work project is emergency response. As an example, firefighting was selected. This involves the integration of wearable technologies such as head-mounted displays, wireless communication, physiological and environmental sensors, on-body computing, and sensor networks, into clothing or personal equipment of firemen. The wearable computing equipment should be as unobtrusive as possible, such that firefighting teams can concentrate on the tasks at hand, but should profit from additional information, warning, and communication facilities. The environment in which the technology is going to operate is extremely challenging, e.g. a big fire with lots of smoke, fire extinction materials, and many impacted persons. Examples of new kinds of support – in part detected during the game-based approach – include heat sensors as early warning of danger from the back of people, enhanced vision through the head-mounted display, and mobile ad-hoc sensor networks.

The staged game-based approach is described in detail in (KLANN 2007), and illustrated in Fig. 22.3. The application partner was the Paris fire brigade.

The initial domain exploration started with grossly oversimplified low-tech games of the application domain which nevertheless are simple and attractive enough to encourage broad initial participation by stakeholders, and sufficient immersive properties to get realistic reactions.

In the firefighting scenario, a simple boardgame was developed together with the firefighters on an architectural sketch of the building at hand (left part of Fig. 22.3); the gaming situation turned out to be much more helpful than requirements or scenarios extracted from individual firemen because each fireman has specific expertise and competence, and the gaming situation brought out this expertise and associated debates among the firefighters in a very realistic and natural way, without being distracted by possible shortcomings of prototype technologies. Indeed, the only pervasive-computing enhancement in this first stage was automated tracking of game agents (firefighters and mobile equipment) using RFID technology. The automated documentation of the game settings was linked to the captured debates and resulting requirements using standard requirements traceability technology (RAMESH & JARKE 2001), specifically the commercial atlas.ti toolkit.

These games guided the first rough design decisions and basic solution architectures. Within this now more limited context, iteratively narrower but more realistic and technically more sophisticated games can be developed and more detailed design decisions can be derived from the play.

In the firefighting case, the second step was a stationary virtual reality game (middle of Fig. 22.3) in which the firefighting intervention could be simulated in 3D with good quality interactive graphics, and with some practical immersion through use of existing or experimental real equipment with realistic limitations.

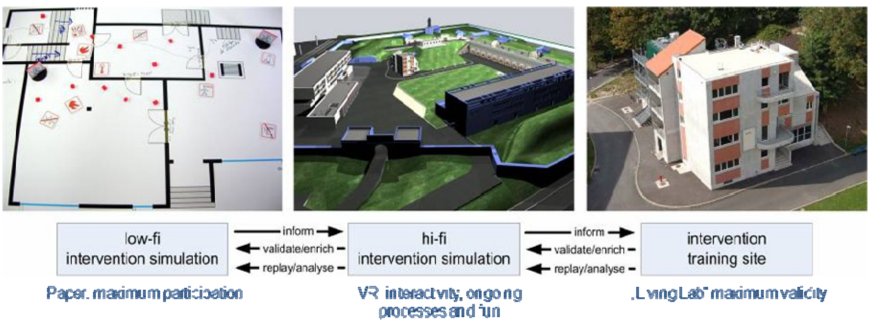

Fig. 22.3: stepwise approximation of reality in game-based design in the firefighting scenario of the European wearIT@work project (KLANN 2007)

In this second step which is illustrated in Fig. 22.4, the player navigates a virtual firefighter through the virtual environment of the highrise in which the virtual fire takes place, modeled after the “Living Lab” training building the Paris firebrigade uses for actual practicing of firefighting (right part of Fig. 22.3).

During the navigation, the virtual firefighter automatically distributes a virtual sensor network. Similar to the breadcrumb approach followed in the “Hänsel and Gretel” fairytale, this sensor network enables relative positioning and backtracking, as well as facilitating communication and environmental sensing. Incidentally, the backtracking enabled by this solution turned out to be one of the most important practical innovations for backtracking your way under difficult conditions. It is far superior to the traditional uses of an “Ariadne file” which gets you in trouble when e.g. you have moved in a circle. To make the experience more realistic in the sense of pervasive computing, the player wears a real head-mounted display which is linked to the virtual sensor network by a wearable computer and receives information from it. Thus, navigation assistance is provided only to the degree that would likely be available in reality. In addition, the virtual reality model is linked to the prototype of a real command post system which, among other things, also receives information from the sensor network and represents them as localized information on a building map.

The point of this game setting is that it can interactively and realistically test the functions and obstacles of the sensor network even though this technology does not yet exist for this very demanding application field. The realistic setting also helps keeping the future users involved in the design in a sustainable manner, as the VR simulation underlying the game can be changed with changing design decisions and assumptions about the environment. Feedback from many unsupervised (by the developers) rounds of play is an important outcome at this stage, not only for the developers but also to stimulate a collective, autonomous reflection and discussion in the intended user community.

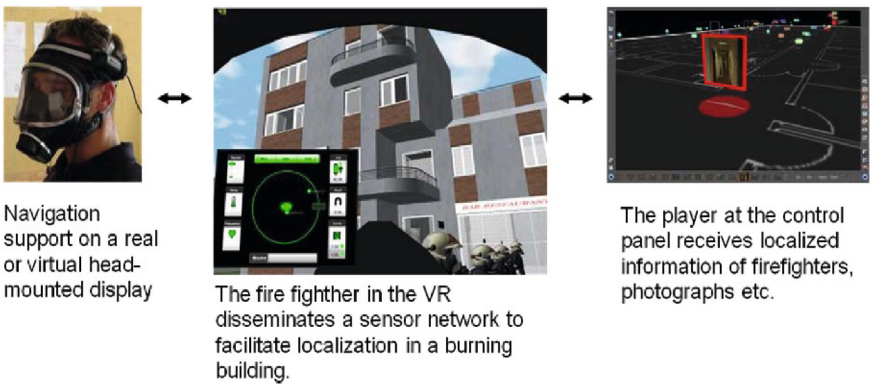

Fig. 22.4: Facets of the FireSim second stage serious game for firefighting scenarios

In the last stage, indicated on the right of Fig. 22.3, the virtual part shrinks further and the physical part grows in importance, as larger and larger part of the developed technologies are tested in real firefighting exercises in the Living Lab of the training building.

This latter stage is just being reached at the time of this writing in the FireSim scenario. However, experiences from less life-critical pervasive gaming application such as the community-based mobile outdoor sports training assistant MOBOTA developed at Fraunhofer FIT (HAHNEN et al. 2006) indicate that this stage will lead to further ideas for design optimization as well as to further increased acceptance. Of course, traceability within and across the different game stages remains crucial throughout.

In summary, the staged pervasive gaming approach to innovation design aims at three important advantages which can be characterized as (a) continuous shared mutual understanding of the co-evolution between technology development and usage context among future users and technology designers, (b) participatory design of innovative yet usable solutions, and (c) designing for the complete user experience rather than just local pieces of it (KLANN 2007).

4 Conclusion

Many early experiments with computer-based business games or with stationary war-room like settings have already shown that the use of serious gaming is a promising extension to traditional scenario- and prototyping-based strategies in the intertwined requirements analysis and early design of complex socio-technical systems. As software-intensive embedded application systems get more pervasive, complex and mobile, the gaming technologies used can and should follow this trend. In this paper, we have reported on some early experiments concerning both the development and evaluation of such pervasive gaming techniques themselves, and their usage in complex socio-technical innovation design.

The experiences indicate, however, that often it may be better not to start with the most sophisticated gaming technologies as they tend to be expensive and to fix too many implementation choices too early. Instead, simple games that leave a lot of room for imagination while still exposing some key features of the application domain may be a better starting point from which then more specific realistic pervasive games can be derived and played.

In current interdisciplinary research with communication researchers and psychologists, conducted in the context of RWTH Aachen's Humans and Technology (HumTec) initiative, we are attempting to turn some of these experiences around by asking the question how pervasive gaming can expose some fundamentals of the human "natural media" which can be considered as determinants, basic constraints and opportunities for the acceptance of future pervasive applications, and as a basis for improving the accessibility of technologies to human diversity in the user population.

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Part 4
Holistic Activities and Work Forms

23 Use of Design Equations for Analyzing User Requirements in Process Control

Martin G. Helander, Shuan Lo

1 Introduction

SUH (1990) presented a design framework that is known as axiomatic design (AD). The goal of AD was to establish a scientific basis for design and to improve design activities by providing the designer with a theoretical foundation based on logical thought processes (SUH 2001). Since 1990, many applications of AD have been reported in various fields of study (e.g. TATE 2000, EL-HAIK & TATE 2002).

Based on the AD framework LO and HELANDER (2007) adapted the metrology so that it could be used for analyzing human-system interaction. The method is called DESA, which is short for Design Equations for Systems Analysis. Using several examples the authors demonstrated how DESA can be used to analyze couplings between the goals that a user or operator wants to achieve, and the control actions that are allowed by a human-machine interface. We noted that couplings between FRs and DPs are always problematic in Human-Machine Systems, since they will lead to iterative control actions, which are time consuming and may cause operator errors (LO & HELANDER 2006). With DESA, the sources of couplings can easily be identified, and alternative design parameters can be suggested, which can remove the coupling and thereby make it easier for an operator to perform a task.

DESA hence offers a promising approach in that the method can explicitly identify design problems, which are based on couplings between design parameters. It also has the potential to facilitate analytical discussions among members of a design team. Thereby, the outcome of a DESA analysis can provide rational criteria, which facilitate early systems evaluations. This type of analysis can be performed by experienced as well as inexperienced designers. While good design solutions depend on the designers' experience, the revelation of poor design solutions is simplified through the DESA methodology and does not necessarily require design expertise.

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2 Purpose and Objective

A method that is useful to some researchers may be difficult to use or vague in concept to others (WILSON 1995). The purpose of this study was to investigate the usability of DESA. We used DESA to analyze problems in process control. These problems are coupled and complex and therefore difficult to solve.

Given the difficulty in problem solving one would anticipate that there could be many proposed design solutions. The study therefore aimed at understanding inconsistency in usage, and why the outcomes vary between individuals who use DESA to model a given system.

A second purpose was to identify potential problems that one may encounter in the use of DESA and recommend future research for improving the method.

3 Use of Design Equations for Systems Analysis

This section provides a brief introduction to the framework of DESA (Helander 2007). There are four design domains in the DESA (see Fig. 23.1). Each of the four domain contains a unique set of design attributes that can be used to describe different aspects of a system. There is a sequential development and specification of design – from User Goals to Functional Requirements to Design Parameters and ending in User Actions. Hence our interest was not just to develop a useful design, but also to model how operators use the framework.

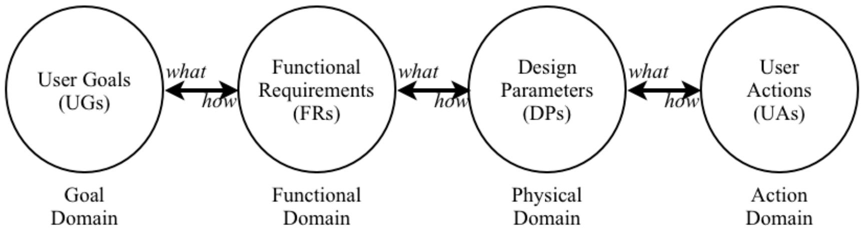

Fig. 23.1: The DESA framework consists of four design domains. There is a means-ends relationship between each pair of adjacent domains. This is expressed by the questions "what" and "how"

To illustrate the characteristics of the framework in Fig. 23.1, we can employ the example of a variable-illumination ceiling light. The goal domain describes a user's desired state or the User Goals (UGs); in our case: "Desired amount of illumination in a room". The functional domain contains Functional Requirements (FRs), which elaborate on the purpose. A design engineer may further clarify the goal, and specify FRs; for example: "Provide a range of 400–800 lux illumination"

The physical domain specifies design parameters (DPs). These are physical embodiments or variables that are selected by a designer to satisfy the FRs. In our case an appropriate DP would be: “Use an electrical rheostat”.

The action domain specifies User Actions (UAs) that are designed into a user interface for controlling the DPs, such as: “Turn rheostat”.

Between each pair of adjacent design domains in Fig. 23.1, the domain on the left describes the ends; expressed by the question What? The domain on the right describes the means, expressed by the question How? Mapping from the goal domain to the functional domain represents a functional specification. Mapping from the functional domain to the physical domain represents an engineering design decisions. Mapping from the physical domain to the action domain represents decision-making regarding the design of human-machine interface. Hence the UGs and UAs describe a human-machine system from a user’s perspective, and FRs and DPs describe a system from an engineering perspective.

Design equations are used to represent the mapping between the four design domains:

$$[UG] = [A][FR] \tag{23.1}$$

$$[FR] = [B][DP] \tag{23.2}$$

$$[DP] = [C][UA] \tag{23.3}$$

where [UG] is a vector of user goals, [FR] is a vector of functional requirements, [DP] is a vector of design parameters, and [UA] is a vector of user actions. [A], [B], and [C] are design matrices. A design matrix such as [B] is of the following form, see (23.4):

$$[B] = \begin{bmatrix} b_{11} & b_{12} & . & b_{1n} \\ b_{21} & b_{22} & . & b_{2n} \\ . & . & . & . \\ b_{m1} & b_{m2} & . & b_{mn} \end{bmatrix} \tag{23.4}$$

where m is the number of FRs and n is the number of DPs.

In axiomatic design there is a recommendation that the number of DPs should equal the number of FRs. If this is not the case the design will be coupled. Hence there is a general endorsement to use problems with a design matrix of order nxn. In our study of the Duress system it turned out that the design matrix is of order nxm, and we therefore needed to address the characteristics of both symmetrical and non-symmetrical design matrices.

Each matrix element b_{ij} is used to relate a component of the FR vector to a component of the DP vector. Typically, a design matrix is expressed qualitatively as shown in Eq. (23.5). “1” or “X” indicates that the column’s DP affects the row’s FR, while “O” or “blank” indicates that it does not. In Eq. (23.5), DP_1 affects all three FRs, while DP_2 affects only FR_2, and DP_3 affects only FR_3.

$$\begin{bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{bmatrix} = \begin{bmatrix} X & & \\ X & X & \\ X & & X \end{bmatrix} \begin{bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{bmatrix} \qquad (23.5)$$

Based on the topographical structure of the design matrices, the mapping between the design domains can be classified as Uncoupled, Semi-coupled, or Coupled (SUH 1990). A design matrix with a diagonal matrix is Uncoupled, meaning that there is a unique relationship between each FR and DP. A design matrix with more elements is Coupled, meaning that one must use an iterative process to find an acceptable set of combinations of DPs in order to satisfy the FRs. In a Semi-coupled design the diagonal elements and the elements below the diagonal contain an X.

According to SUH (1990), designers should always avoid design solutions that are coupled. Coupling has been identified as a generic dimension of complexity (e.g. ENDSLEY 1995, MILLER 2000, WOODS 1988). WIERINGA and STASSEN (1993) suggested that the complexity of a system can be characterized according to the number of functions and the degree of coupling between the functions. In DESA, a coupling between UGs and UAs is perceived as a deciding factor in increasing the "gulf of execution" of a human-machine system (NORMAN 1988).

4 Procedure

Ten university engineering students from Nanyang Technological University participated in this study. Each participant was identified by a letter from A to J. Participant C was an undergraduate student in his senior year; while the others were graduate students. The age of the participants ranged from 23 to 35. Three of the participants were female. Participants D and I had attended an introductory class in axiomatic design (AD); while the others had no knowledge of AD. Three experimental sessions were conducted with 3–4 students in each. The procedures for the three sessions were identical. Each session lasted for about 100 minutes. Before the start of each session, the participants were briefed on the objectives of the study, and their consent to participate was obtained. Each test subject was paid $25 for their participation.

Each session consisted of two phases. In the first phase, the participants were asked to study a set of instruction notes (about 1000 words) that explained the basic concepts of DESA. The design of a simple manual camera and two different types of water faucet were modeled using DESA and presented as explanation aids in the notes. At the end of the session, an adjustable microscope workstation was presented together with its user goals (UGs) and its functional requirements (FRs). As an exercise to test the participants' understanding of the concepts, the participants were asked to work independently to identify the interactions between the

UGs and the FRs and to construct a design matrix that represents these interactions. After the participants finished the exercise, the correct answer to the exercise was explained to the participants, and they were encouraged to ask questions about the procedure.

In the second phase, a textual and graphical description of DURESS II (Dual Reservoir System Simulation) was presented to the participants (VICENTE 1999). DURESS II is a thermal-hydraulic microworld that was designed to model industrial processes (see Fig. 23.2). It has two redundant feedwater streams that can be configured to supply water to two reservoirs. Thereby a feedwater stream can supply one of the reservoirs, both of them or none of them. The operator of the system can also control two heaters and up to eight valves to achieve a prescribed set of temperature and water output at each of the reservoirs. The output of each reservoir is marked VO1 and VO2 respectively, see Fig. 23.2.

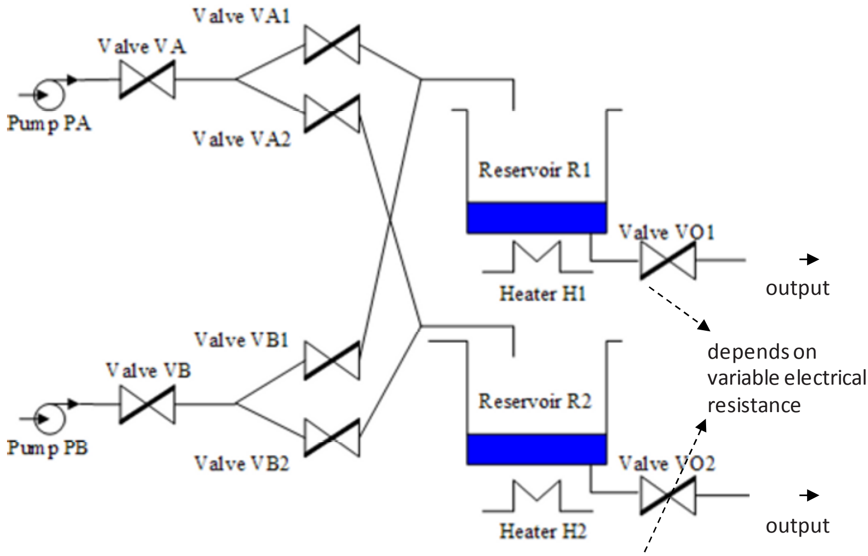

Fig. 23.2: A schematic diagram of the DURESS II (adapted from VICENTE 1999)

Subsequently, the participants were presented with three process control system configurations (see Fig. 23.3). These configurations were constructed by removing some of the valves and pipes in DURESS II. VICENTE (1999) referred to such configurations as configurations strategies. The UGs and UAs for each of the configurations were provided to the participants (see Tables 23.1 and 23.2). The participants were then asked to specify the FRs and DPs, and to construct the design matrices [A], [B], and [C] for each configuration (see Eqs. 23.1 to 23.3 above).

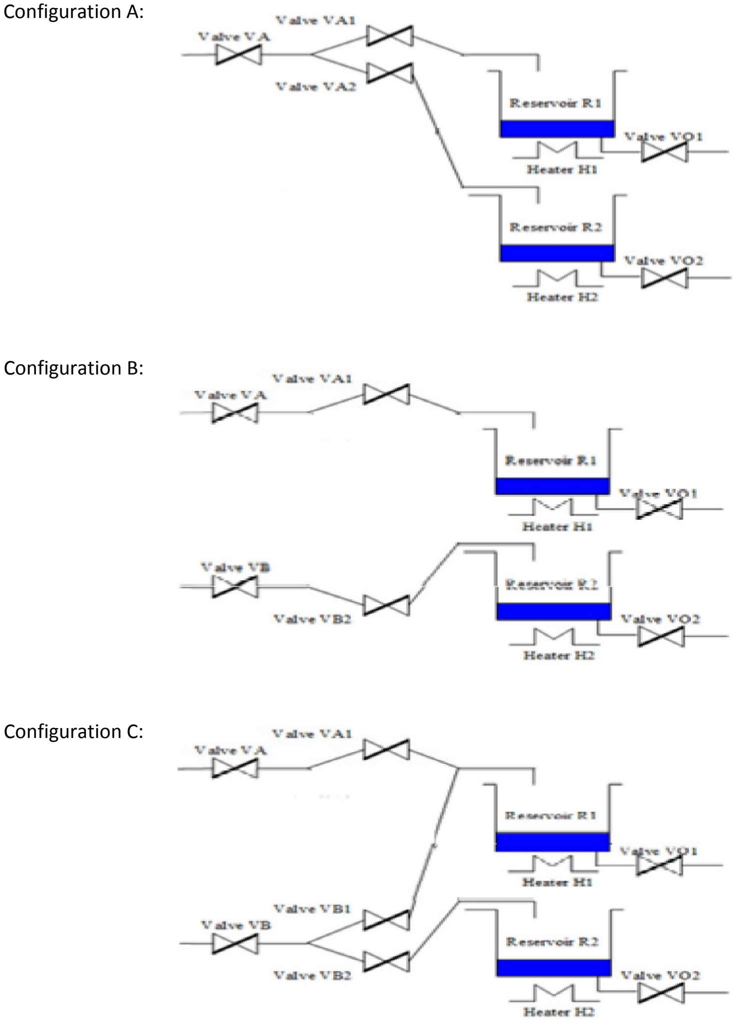

Fig. 23.3: Three configurations of process control system based on DURESS II. There are 5, 6, and 7 valves

Table 23.1: Prescribed User Goals (UGs) for configurations A, B, and C

UG_1:	Desired output water flow rate at reservoir R1
UG_2:	Desired output water flow rate at reservoir R2
UG_3:	Desired temperature in reservoir R1
UG_4:	Desired temperature in reservoir R2

Table 23.2: Prescribed User Actions UAs for configurations A, B, and C

Configuration A	Configuration B	Configuration C
UA_1: Control orifice size of valve VA	UA_1: Control orifice size of valve VA	UA_1: Control orifice size of valve VA
UA_2: Control orifice size of valve VA1	UA_2: Control orifice size of valve VA1	UA_2: Control orifice size of valve VA1
UA_3: Control orifice size of valve VO1	UA_3: Control orifice size of valve VO1	UA_3: Control orifice size of valve VO1
UA_4: Control orifice size of valve VA2	UA_4: Control orifice size of valve VB	UA_4: Control orifice size of valve VB
UA_5: Control orifice size of valve VO2	UA_5: Control orifice size of valve VB2	UA_5: Control orifice size of valve VB1
UA_6: Control heater H2 at reservoir R1	UA_6: Control orifice size of valve VO2	UA_6: Control orifice size of valve VB2
UA_7: Control heater H2 at reservoir R2	UA_7: Control heater H2 at reservoir R1	UA_7: Control orifice size of valve VO2
	UA_8: Control heater H2 at reservoir R2	UA_8: Control heater H1 at reservoir R1
		UA_9: Control heater H2 at reservoir R2

We selected DURESS II for this study because it has some coupling and redundancy, but it is still simple enough for the participants to understand how it works.

The rationale of asking the participants to model three different configurations of the process control system was twofold. First, we wanted to give the participants an opportunity to check the consistency of their models. Second, we wished to know how the participants would perceive the differences between the three configurations – would they think that the systems were different in terms of FRs, DPs, or both?

5 Results

5.1 Number of FRs and DPs

In terms of number of FRs for each of the three system configurations, two distinct patterns were identified (see Table 23.3). Seven of the participants formulated seven FRs for configuration A, eight FRs for configuration B, and nine FRs for configuration C. This was called Pattern 1.

The other three participants formulated four FRs for each of the configurations. This was called Pattern 2.

In terms of number of DPs, there were no differences among subjects for each of the configurations.

Table 23.3: Number of FRs and DPs that were formulated by the participants to describe each of the three system configurations

	Configuration A	Configuration B	Configuration C
Pattern 1- Flow Rate:	7 FRs	8 FRs	9 FRs
Participants A, B, C, D, E, F, G	7 DPs	8 DPs	9 DPs
Pattern 2- Heat Transfer:	4 FRs	4 FRs	4 FRs
Participants H, I, J	7 DPs	8DPs	9 DPs

5.2 Expression of FRs and DPs

The FRs and DPs specified by the participants, except for participant B, can be classified into two types:

(1) FRs and DPs related mainly to the water flow rate or the valves in the system, and

(2) FRs and DPs that are related mainly to the heat transfer rate or the heaters in the systems.

Regardless of the system configuration that was being modeled, each participant, except for participant B, had a consistent way of expressing the FRs and DPs within each of these types. Table 23.4 illustrates the expressions that were used by the participants. For instance, participant in Pattern A expressed all type 1 FRs in terms of “provide user control for flow rate at (valve name)” and all type 1 DPs in terms of “orifice size of (valve name)”.

Table 23.4: Typical FRs and DPs expressions from the participants

	Type 1 FR	Type 2 FR	Type 1 DP	Type 2 DP
Participant A	provide user control for flow rate at VA	provide user control for heat at H1	orifice size of VA	power supplied by H1
Participant B	Inconsistent expressions across system configurations. This subject was deleted			
Participant C	provide user control of orifice size VA	provide user control for heater H1 at R1	orifice size of VA	variable electrical resistance of H1
Participant D	having control for VA	having control for H1	adjustment knob for controlling VA	adjustment knob for controlling H1
Participant E	provide user control to adjust flow rate at VA	provide temperature controller at H1	orifice size of VA	controllable heater H1
Participant F	adjustability of VA	adjustability of H1	orifice size of VA	electrical resistance of H1
Participant G	provide user control for orifice size VA	provide user control for temperature of heater 1	orifice size of VA	H1 at R1
Participant H	provide the control of output flow rate of R1	provide the control of water amount and heat for R1	flow rate across VA	heat amount of H1
Participant I	provide user control for desired flow rate in R1	provide user control for desired temperature in R1	size of orifice VA	temperature of H1 in R1
Participant J	provide user control output water flow rate at R1	provide user control temperature in R1	orifice size of VA	heater power of H1

The expressions of FRs used by participant B were not consistent across the system configurations (see Table 23.5). For instance, type I FRs for configuration A were in the form of “control flow rate in (valve name)”, but type 1 FRs for configuration B were in the form of “control diameter of (valve name)”. Although the flow rate across a valve is dependent on the diameter of the valve, the semantics of the two expressions are not exactly the same. In addition, participant B expressed several FRs as combinations of two or more independent FRs, such as “control heater temperature in (heater name) and flow rate through (valve name X) and (valve name Y)”. These suggest that participant B either did not understand the mechanics of the process control systems or the basic concepts of DESA. His solutions were not included in the following analysis.

Table 23.5: Expression of FRs and DPs from participant B across the three system configurations

Configu-ration	Type 1 FR	Combinations of two or more FRs	Type 1 DP	Type 2 DP
A	control flow rate in VA	control temperature (+ flow rate in R1)	diameter size of aperture of VA	resistance of heater coil H1
B	control diameter. Of VO1	control temp and flow from VA1 and VO1	diameter of VA	resistance of heating coil of H1
C	control size of VO1	control heater temp in H1 and flow rate through VA1 and VB1	diameter of VA	heater resistance in H1

6 Analysis

6.1 Inconsistency in Number of FRs

It seems likely that the inconsistency between participants in terms of number of FRs for each system configurations is related to the issue of abstraction levels. According to SUH (1990), a design description can consist of multiple abstraction levels. The higher levels are more abstract; the lower levels are more detailed. At each level, there is a set of FRs. To decompose this set of FRs, a designer needs to identify the set of corresponding DPs at the same level. Suh referred to this decomposition process, which alternates between design domains, as “zigzagging” (see Fig. 23.4). For example the decomposition of FR1 into two sub-FRs, FR11 and FR12 depends on FR1 as well as the design parameter DP1. In this study, the participants were not taught how to model a system in more than one abstraction level, and the examples in the study notes used one abstraction level only. However, participants D and I were familiar with AD, so at least the two of them knew about zigzagging.

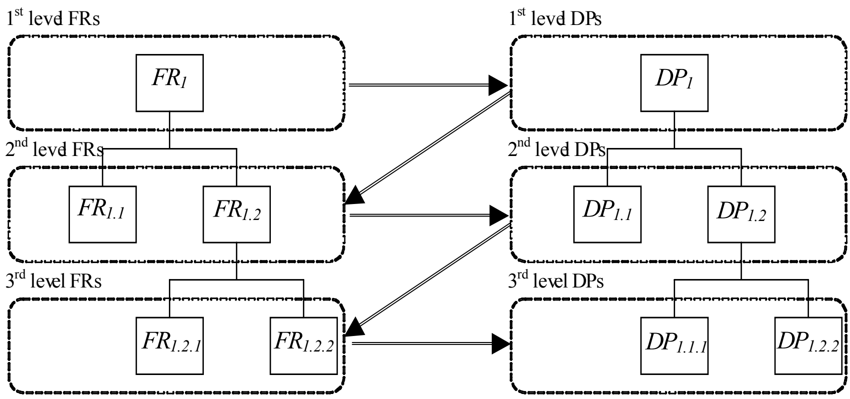

Fig. 23.4: A design description usually consists of several abstraction levels. The lower level FRs and DPs s depend on the higher level FRs and DPs

The FRs specified by participants in pattern A appear to be decomposed from the FRs specified by participants in pattern B; that is, the FRs in pattern A are of a lower abstraction level. The FRs in pattern B are more abstract in the sense that they refer to the overall functions of the process control system: to provide control for output water flow rate and output water temperature and the higher level goals. The FRs in pattern A are more detailed in the sense that they are specified with respect to the DPs that satisfy the FRs in pattern B.

For instance, participant H, who is classified under pattern B, stated "provide the control of output flow rate of R1" as one of the FRs for system configuration A. He then specified the orifice size of the valves that affect the output flow rate at R1, such as valve VA, as the DPs that are related to this FR.

Participant G, who is classified under pattern B, stated one of his FRs for configuration A as "provide user control for orifice size VA".

We see a zigzagging relationship from participant H's FR to his DP to participant G's FR (see Fig. 23.5). This explains why the number of FRs specified by participants in pattern A is dependent on the number of valves used in the system configurations, while the number of FRs specified by participants in pattern B are the same for all the configurations; the lower level FRs depend on the higher level DPs.

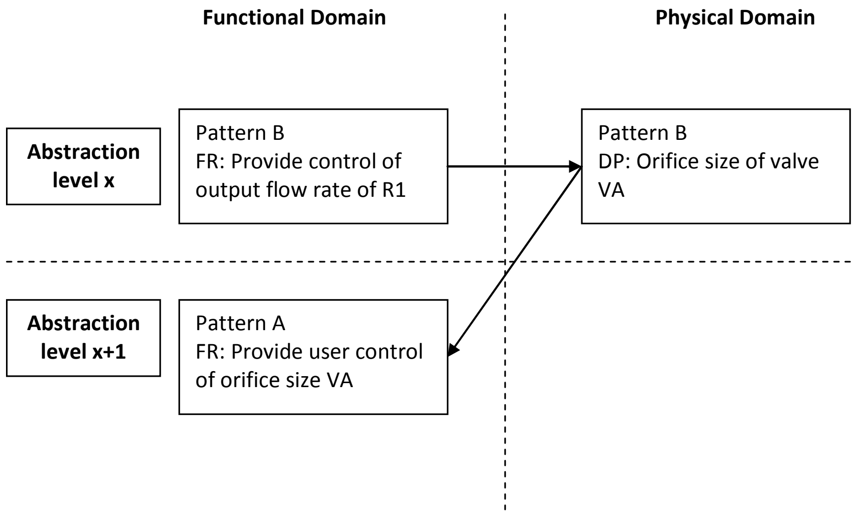

Fig. 23.5: Compared to the FRs specified by participants in pattern B, the FRs specified by participants in pattern A appear to be at a lower level of abstraction

The number of DPs for each system configuration was consistent between the participants. We think this is because of the schematic illustrations of the system configurations that were provided made it straightforward for the participants to identify the valves and heaters as the key physical components in the system.

6.2 Semantics of the FRs and DPs

In Sect. 4 we classified the FRs and DPs into Type 1 and Type 2. The FRs and DPs within these two types can be further classified according to their object of reference (see Table 23.6).

Table 23.6 shows that the FRs and DPs formulated by the nine participants vary widely. For instance, type 1b FRs are with reference to system physical variables, such as water flow rates, while the other types of FRs are with reference to system process parameters, such as reservoir temperature. Types 1b and 2b DPs are with reference to user interface components, while other types of DPs are with reference to either system physical variables, such as valve orifice size, or system process parameters, such as heater temperature. Therefore, while the number of DPs specified by the participants for each system configurations is consistent, the semantics of the DPs are not.

Table 23.6: Classification of FRs and DPs according to the object of reference

	Functional requirements	Design parameters
Type 1	Type 1a: With reference to the flow rate across a valve (participants A and E)	Type 1a: With reference to orifice size of valve (participants A, C, E, F, G, I, J)
	Type 1b: With reference to the orifice size of valve (participants C, D, F, and G)	Type 1b: With reference to user interface component for controlling valve (participant D)
	Type 1c: With reference to output water flow rate of reservoir (participants H, I, and J)	Type 1c: With reference to water flow rate across valve (participant H)
Type 2	Type 2a: With reference to heat produced by heater (participants A, C, D, E, F, and G)	Type 2a: With reference to power output or electrical resistance of heater (participants A, C, F, J)
	Type 2b: With reference to ratio of amount of heat energy to mass of water in reservoir (participant H)	Type 2b: With reference to user interface component for controlling heater (participant D)
	Type 2c: With reference to reservoir temperature (participants I and J)	Type 2c: With reference to adjustable heater (participants E, G)
		Type 2d: With reference to temperature of heater (participants H and I)

7 Discussion

The results of this study were consistent with our expectations; the participants interpreted DESA and specified the FRs and DPs of the process control systems differently. Therefore, there is a need to devise means for minimizing this type of variability, so as to enhance the reliability and acceptability of DESA as a tool for systems analysis.

The inconsistencies in the FRs that were formulated by the participants highlight the importance of the zigzagging concept. One main difficulty for the users was to define and use abstraction levels in design. As a rule of thumb, FRs in one abstraction level should not constitute the DPs that belong to the same level; FRs are the ends, DPs are the means (see Fig. 23.1). The results also suggest a need that in training the use of DESA, the FRs should be formulated independent of one another and DPs are not user interface elements. However, since FRs are formulated using natural language, independence of FRs will be difficult to judge in some cases.

The zigzagging concept is related to design abstraction, which is a construct that is important and prevalent in design theories and methodologies. Modeling a system in terms of abstraction levels is helpful in dealing with the complexity of the system; one can temporarily focus on the information contained in one or two abstraction levels and ignore the others. However, there are not many theories or methods in the literature that design engineers can use to identify or differentiate between abstraction levels in design.

A definition of design abstraction level was proposed by BRAHA and MAIMON (1998):

$$A = \frac{H_i}{H_f} \tag{23.6}$$

where H_i is the information content of the initial state and H_f is the information content of the current state. Measuring the information content of a design is not something that design engineers are usually trained to do. Nevertheless, we see this definition as having the potential to be developed into a more explicit and rational methodology that design engineers can use.

Although the number of DPs specified by the participants is consistent between participants and across systems configurations, the semantics of the DPs are not. Some DPs refer to physical system components such as valves, others refer to system process parameters such as reservoir temperature. This type of inconsistency is also related to design abstraction levels, and we see the potential of using RASMUSSEN'S et al. (1994) abstraction hierarchy (AH) to guide DESA users. There are five abstraction levels in AH. Each level is defined and Rasmussen provides several prototypical examples. Future research should investigate how these five levels can be integrated with the concept of design hierarchy in AD and thereby DESA.

The purpose of this study was to investigate the usability of DESA. We used DESA to analyze problems in process control. These problems are coupled and complex and therefore difficult to solve.

Given the difficulty in problem solving one would anticipate that there could be many proposed design solutions. The study therefore aimed at understanding inconsistency in usage, and why the outcomes vary between individuals who use DESA to model a given system.

A second purpose was to identify potential problems that one may encounter in the use of DESA and recommend future research for improving the method.

In conclusion, this study reveals a need to provide guidance on how to construct, validate, and revise a DESA model. The guidance could be in the form of procedures and guidelines. Refining the existing definitions in DESA is also one possible approach that can be used to improve the explicitness of this methodology. It is important to point out that the results of this study could be different if the training materials were presented in a different manner, such that the study participants were professional design engineers, or the object of modeling was of a different nature. Therefore, there is a limit to how much one can conclude from this study. Nevertheless, this is a first and important step to determining and improving the usability and reliability of DESA. In future studies we will expand on the present approach.

In addition the study results revealed that there a need to instruct and train users in how to construct, validate, and revise a DESA model.

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24 Action Regulation Theory: Are the Characteristics of Well Designed Tasks Valid for Interactive Jobs as Well? – The Concept of Two-dimensional Task Identity in Interactive Work

Winfried Hacker, Marlen Melzer

1 Introduction

One of the crucial concepts of Action Theory is task identity, i.e. the completeness vs. fragmentation of tasks (FRESE & SABINI 1985, HACKER 1985).

The completeness vs. fragmentation is a consequence of two basic concepts: Firstly, the approach of the allocation of functions between employees and machines and secondly, the approach of the division of the remaining labor between employees.

From a psychological point of view the concept of task completeness vs. fragmentation may be operationalized following two aspects. The first aspect is that of sequential completeness. There the question is whether or not a task includes the phases of goal setting, scheduling and planning, organization of cooperation, implementation and checking of process and result, or implementation only (Fig. 24.1).

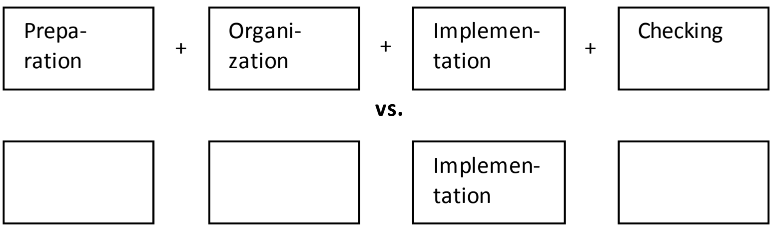

Fig. 24.1: The sequential aspect of task completeness vs. fragmentation

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The second aspect of task completeness vs. fragmentation is the heterarchical one. It describes, whether or not *all* modes of mental regulation are involved in action regulation, i.e. carrying out the working task requires regulation on the intellectual mode (e.g. reasoning or problem-solving), the knowledge, or experience based mode (i.e. regulation by explicit declarative and procedural knowledge) or the automatic vs. automated one (i.e. regulation by implicit routines).

The approach of sequentially and heterarchically complete vs. fragmented tasks became the basic issue of International and European standards on "well-designed working tasks" (DIN EN ISO 9241-2: 1992, DIN EN 614-2: 2000), standards governing the analysis, evaluation and design of working tasks.

The central demand of these standards is that working tasks ought to be complete, wholistic and meaningful units of work, rather than fragments of those. They should contribute meaningfully to the overall outcome of the organization and provide an appropriate variety of skills and abilities, whereupon *routine-based, knowledge-/or rule-based* as well as *problem-solving* (*intellectual*) activities should be adequately combined. Repetitive, monotonous tasks are to be avoided. Further, the working tasks should provide adequate job discretion or control as regards to the speed of working, the sequence of subtasks, and way of proceeding, as well as sufficient and meaningful feedback. Moreover, the tasks should consider the working individuals knowledge, experience, skills, and abilities in order to avoid overload or underload and provide opportunities for the utilization and development of *existing* as well as the acquisition of *new* knowledge, experience, skills, and abilities. Finally, socially isolating work ought to be avoided.

These standards are conceptually rooted among others in the contributions by SCHWEITZER (1971), VOLPERT (1974), FRESE and SABINI (1985) and HACKER (1980, 2005).

Extensive empirical support for the standards has been provided e.g. by HOLMAN AND WALL (2002), MORRISON et al. (2005), PARKER (2003) and VAN DER DOEF & MAES (1999).

The core characteristic of the standards is the *completeness* of the task. The further characteristics demanded by the standards are strongly associated with this core characteristic.

However, in spite of their generic wording the standards have originally been developed for tasks associated with operating machines and visual display unit (VDU) tasks – i.e. for object-centred, monological tasks, only. Therefore fundamental modifications might be inevitable in order to transfer these standards on "well-designed tasks" to human service work, the majority of employees nowadays are engaged in.

In our case, the transferability to a specific type of service work is to be tested: retail sales tasks.

Even though retail tasks have been investigated in several studies (e.g. NERDINGER 2001, TOLICH 1993, VOSS-DAHM & LEHNDORFF 2003, ZÜLCH et al. 2005), there are so far no detailed analyses on the mental demands of this specific class of activities, which are indispensable in the analysis of working activities in the service sector as well (LUCZAK et al. 2005).

Several authors point at the necessity of work-related emotion regulation and the risk for emotional dissonance in interactive service tasks associated with customer contact (e.g. GRANDEY et al. 2004, ZAPF 2002). However, there is so far no empirical research on these work requirements in retail sales.

Whereas monological tasks, e.g. operating a lath, *change objects*, and interactive (dialogical) service tasks, e.g. nursing, *change subjects*, the subject matter of retail tasks is neither changing objects nor changing subjects, but *ex*changing goods and currency.

Retail tasks consist *both* of interaction-centred subtasks – e.g. serving the customer, advising or cashing – as well as object-centred ones – e.g. putting up or ordering goods. Thus, a modification of the concept of task identity, i.e. the completeness vs. fragmentation of working tasks, is suggested.

For the *object-centred* subtasks the established grading of task completeness according to the degree of the division of labor known from research on monological tasks is being used. Accordingly, predominantly executing subtasks are distinguished from scheduling and checking in completely processing or producing a work result.

For the *interaction-centred* subtasks we developed a grading that results from the *completeness of customer interaction:*

A complete customer interaction in retail sales consists of firstly *serving* the customer, i.e. investigating and meeting his buying desire as well as providing routine information, secondly *advising* the customer, i.e. supporting his purchase decision, as well as thirdly *cashing*.

This complete sales interaction is represented by alternative F in Table 24.1.

The division of labor may result in *incomplete* sales interactions.

For example, alternative B represents a retail task with customer interaction merely consisting in cashing.

Alternative D describes a retail task which includes serving the customer and cashing, but not advising.

With this grading the interaction-centred task completeness vs. fragmentation is being introduced as a *second dimension* of task completeness. Its combination with the object-centred task completeness bears a two-dimensional system of "*extended task completeness*". Working tasks in retail sales may thus be described as configurations of object-centred and interaction-centred subtasks that differ in their task completeness vs. fragmentation.

We assume that complete exchange tasks are associated with more favorable perceived task characteristics and mental well-being than fragmented ones – as well known for other types of working tasks (HACKMAN & OLDHAM 1976, HOLMAN & WALL 2002, HUMPHREY et al. 2007).

2 Questions and Hypotheses

Thus, our main questions and hypotheses are:

(1) Do the hypothetically predicted configurations of differently complete object- and interaction-centred tasks actually exist in the investigated sample of retail tasks, and how frequent do they occur?

(2) Do configurations of differently complete retail tasks differ with regard to the employees' perceived characteristics? We assume: Analogously to the findings concerning other types of working tasks (e.g. HOLMAN & WALL 2002) we assume that sales people engaged in complete retail tasks perceive regulation requirements and opportunities, learning opportunities, opportunities for qualification use and regulation difficulties in their task significantly more comprehensively than sales people engaged in fragmented retail tasks.

(3) Do differently complete retail tasks differ with regard to perceived mental well-being?

(4) We presume that on otherwise equal conditions sales people engaged in complete tasks report significantly less *mental fatigue, mental satiation* and *monotony* than sales people with fragmented tasks.

3 Methods

Sample. In order to answer these questions, 419 sales people (76% females) in different lines and sizes of retail businesses (44.9% grocery stores, 17.6% hardware and do-it-yourself stores, 10.4% white good stores; 9.3% textile stores; 8.9% drug stores and perfumeries 8.9% others) were examined. Their mean age was 38.5 ± 12.0 years, the duration of their previous professional experience in retail sales was 13.6 ± 10.2 years. The majority of the participants (47.8%) were employed full-time, 32.3% of them part-time. Only 5.8% of the sales people were marginal part-timers. 14.2% of the participants were self-employed shop-owners. Most of the sales people included in the study (88.6%) had an indefinite employment contract; the contract of 11.4% of the participants was a temporary one.

Independent Variable. The object- and interaction-centred subtasks as well as their time slices were investigated using work studies. Based on these data the retail tasks could be assigned to the two-dimensional system of task configurations.

Dependent Variables. The task characteristics perceived by the sales people were analyzed using a self-developed questionnaire based on the international literature as well as on pilot studies in retail sales. It included 30 items representing the characteristics of “well-designed tasks” demanded in the international standards as well as their modification for the interaction-centred subtasks. Data analysis was based on the factors of the set of perceived task characteristics investigated in the study.

Due to its strong emphasis in the international literature on interactive working tasks, emotional dissonance was examined using the scale of the Frankfurt Emotion Work Scales (ZAPF et al. 2000).

Short-term mental strain was acquired using the rating scales proposed by RICHTER et al. (2002).

Mid-term mental strain was investigated using the scale “Emotional Exhaustion” of a translation of Maslach Burnout Inventory (MBI) by SCHAUFELI et al. (1996).

4 Results

Configurations of two-dimensional task identity. The results concerning the actual occurrence as well as the frequencies of the hypothetically distinguished task configurations in the investigated sample show: All retail tasks can be assigned to the hypothetical two-dimensional system of extended task completeness (Table 24.2). Thus, the concept of extended task completeness vs. fragmentation is appropriate to classify retail tasks. The majority of the examined retail tasks (89.0%) combine interaction-centred with object-centred subtasks.

The results referring to the hypothesized differences between the differently complete retail tasks *with regard to perceived task characteristics* at first necessitate some further information.

Perceived Task Characteristics. Prior to the examination of possible differences between the task configurations the perceived task characteristics were grouped. The exploratory factor analysis resulted in four factors explaining 53% of the total variance. The factors represent perceived regulation requirements and opportunities, perceived learning opportunities, perceived qualification use and perceived regulation difficulties. They correspond to the factors identified by LEITNER et al. (1987) for other classes of activities.

The comparison of the configurations of retail tasks with respect to these factors shows: Sales tasks differing in their two-dimensional completeness actually do differ in perceived task characteristics as well. This holds for the factors perceived regulation requirements and opportunities ($F_{object\text{-}centred}$ [1, 164] = 27.47, $p < .05$; $\eta^2 = 0.15$; $F_{interaction\text{-}centred}$ [1, 164] = 2.67, $p < .10$; $\eta^2 = 0.02$), perceived learning opportunities ($F_{object\text{-}centred}$ [1, 189] = 5.22, $p < .05$; $\eta^2 = 0.03$; $F_{interaction\text{-}centred}$ [1, 189] = 1.94, $p < 0.10$; $\eta^2 = 0.01$) and perceived qualification use ($F_{object\text{-}centred}$ [1, 133] = 5.24, $p < .05$; $\eta^2 = 0.03$; $F_{interaction\text{-}centred}$ [1, 133] = 2.76, $p < .05$; $\eta^2 = 0.02$), as tested by ANOVA´s for the most frequent task configurations. The effect sizes are predominantly small.

In agreement with our hypothesis, perceived regulation requirements and opportunities as well as perceived learning opportunities are perceived more comprehensively in tasks that are complete with regard to their object-centred subtasks as well as tasks that are complete with regard to their interaction-centred subtasks in comparison to the corresponding fragmented tasks. However, there is no significant difference in perceived regulation difficulties.

Contrary to our hypothesis, opportunities for qualification use are perceived more comprehensively by sales people engaged in fragmented rather than complete retail tasks.

There is no significant *interaction* of both dimensions of task completeness with regard to any of the investigated factors of perceived task characteristics.

Perceived mental well-being. Finally, the results referring to perceived mental well-being in the configurations of retail tasks will be lined out.

As the sales people in all task configurations report on average “no” short-term mental strain, the differently complete retail tasks may, thus, not differ significantly with regard to perceived mental strain, i.e. fatigue, mental satiation and monotony.

Analogously, emotional dissonance and – consequently – emotional exhaustion are reported extremely seldom and, thus, may not differ between the configurations of extended task completeness.

5 Discussion and Conclusion

Referring to the main question whether the international standards on “well-designed tasks” (DIN EN ISO 9241-2: 1992; DIN EN 614-2: 2000) for operating machines and visual display unit (VDU) work may be applied for the analysis, evaluation and design of interactive exchange tasks as well, the results suggest the following answers:

The type of interactive tasks of interest here – retail tasks aiming at the exchange of goods and money – may be described by the completeness of customer interaction combined with the completeness of the object-centred subtasks. The hypothetically deduced two-dimensional system of extended task completeness predicts configurations of interactive tasks which actually do exist. Thus, the concept of task identity – the key characteristic of the standards on "well-designed tasks" – *may* be applied to interactive working tasks in retail sales, too.

The two-dimensional system of extended task completeness moreover proves to be suited for the prediction of outcome variables in the working individuals: Retail tasks differing in two-fold task identity significantly *differ* in perceived task characteristics in the expected direction, i.e. sales tasks which are complete with regard to their object- and interaction-centred subtasks are perceived more favorable than the corresponding fragmented tasks. Thus, the concept of task identity is also an appropriate basis for the *design* of retail tasks which are conducive to learning in the job and thus contribute to the employees´ employability (ILMARINEN & TEMPEL 2002) – one of the major outcome variables in jobs with precarious working conditions such as retail sales.

The seemingly contradictory results concerning perceived opportunities for qualification use may be explained by similar findings according to which higher qualified employees may *not* use considerably large parts of their job-related knowledge, skills and experience and, thus, perceive less opportunity for qualification use than lower qualified ones who may utilize most of their qualification.

Further research should concern at least two issues: Firstly, the lacking interaction of the object- and the interaction-centred task completeness ought to be replicated. It could conceptually point at the independence of both dimensions of task completeness vs. fragmentation. In this case, an important consequence for task design would be the mutual compensation in the case of fragmented tasks.

Secondly, the applicability of the concept of extended task completeness to tasks associated with changing clients (i.e. dialogical tasks, e.g. teaching) is to be tested.

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25 Evaluation of the Quality of Job Design with the Action-Oriented Software Tool REBA – Recent Developments and Applications

Peter Richter, Uwe Debitz, Andreas Pohlandt

1 Action Regulation Theory as Basis for Human-Centered Job Design

The basic axioms and features of the action-regulation theory (ART), developed primarily in German, are described in English by HACKER (1985, 2003), and FRESE and ZAPF (1994). Human-centered job design should follow three goals simultaneously (HACKER 2003, HACKER & RICHTER 2006): enhancement of efficiency, from the point of view of both enterprises and employees, optimization of psycho-physiological strain, and enhancement of physical and mental health, including personality development due to the learning potential of the job.

The development of abilities and skills takes place through active processing of tasks. Personality development is to be understood in the sense of:

(1) Preservation and enlargement of qualification, and, especially, of abilities.
(2) Preservation and stimulation of work motivation.
(3) Preservation and strengthening of health as complete physical, mental and social well-being.

This so-called “completeness of regulation structure” (HACKER 2003, HACKER & RICHTER 2006) has a high predictive value for optimization of strain, personality enhancement and work effectiveness. The sequentially complete work structure includes preparation (goal-setting, planning, action programs, autonomous decision-making), execution, checks and organization.

Design deficits in this structure can bring negative consequences, such as stress, fatigue, vital exhaustion, and increased risk of coronary heart disease, depression and higher back pain.

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1.1 Mental Workload

The emphasis of the dynamic and self-organizing process of action regulation is to provide a valid framework for describing the active process of strain regulation and predicting the negative consequences of mental overload and underload. Coping processes for the stabilization of unstable regulation structures could be; reduction of the level of goals and aspirations, reduction of task-specific activation and changes in working strategies. Despite these coping processes, if the regulation structure of actions cannot be stabilized mental overload will have negative effects.

Consequences of negative strain are differentiated as mental fatigue, monotony, mental satiation and reduced vigilance. This system corresponds to the international classification of mental workload consequences in ISO EN DIN 10 075. In this standard stress is defined as the input variable for mental load factors. Therefore, this extended approach will implement stress as highly emotional negative consequence in contrast to mental fatigue. An EU-agreement defined work-related stress "as a state, which is accompanied by physical, psychological or social complaints or dysfunctions and which results from individuals feeling unable to bridge a gap with the requirements or expectations placed on them" (SOCIAL DIALOGUE 2004).

According to these distinctions, the quality of strain consequences and their intensity can be evaluated by means of behavioural and psycho-physiological parameters. Diagnosis of various subjective phenomena is particularly suitable. An interval-scaled questionnaire has been developed for the diagnosis of perceived workload (PLATH & RICHTER 1984). This BMS-questionnaire, meanwhile translated into 6 languages, has proven to be a reliable and valid instrument for rating mental fatigue, monotony, mental satiation and work-related stress, according to the distinctions.

1.2 Human-Centered Job Design

The following ART-oriented recommendations for job design can be derived (e.g. PARKER & WALL 1998):

- allow people a high level of goal-setting in their work
- increase the degree of freedom, giving employees the possibility to control work processes and develop their own work strategies
- ensure task-specific qualification, enabling employees to cope efficiently with work demands
- ensure that the task itself provides feedback loops
- overall: ensure sequential (goal setting, execution, organization of cooperative actions, feedback) and hierarchical completeness of actions.

Human-centered job design is possible by defining the division of function between humans and machines (computer, programs, etc.), the division of labour between different persons, and the forms of cooperation between different employees.

However, work activities are often characterized by integration into a larger technological process: the remaining work activities are frequently subsidiary parts of mechanized and automated technical processes and are therefore subordinate to the laws governing them. Work activities are very often only possible at certain stages in the technical process, i.e. when it is possible for humans to intervene. They are frequently constrained, offering little freedom of choice. Together with their regulative processes and representations, they can be constrained by restrictions of the technological process, by the division of function between human and machine, and moreover by restrictions produced through Tayloristic division of labour between humans.

The main factor which affects the level of regulation is the degree of completeness vs. incompleteness of work activities. The reason for incomplete task structure is the allocation of residual tasks between persons. The incomplete task structure reduces the development possibilities of the intellectual level of regulation (SPIJKERS & LOCHNER 1992).

2 Tools in Human-Centered Job Design – The Task Diagnosis Survey (TDS), REBA 8.1, and the Prediction of Mental Workload

It is possible to differentiate two groups of instruments for the analysis of mental work load and strain (OESTERREICH & VOLPERT 1987): condition-oriented task analysis and person-oriented analysis. The *condition-oriented approach* analyses organizational and technological conditions of action regulation, the cognitive and social demands of tasks. A special German development is the creation of task-related work analysis instruments (observational interviews and document analysis), realized by trained ergonomists or psychologists, which attempt to minimize the subjectivity in questionnaires. A great influence for the development of these instruments came from classical ergonomical approaches (e.g. ROHMERT & LANDAU 1979). The VERA/RHIA instruments (e.g. LEITNER & RESCH 2005), the ISTA method (e.g. SEMMER et al. 1996) and the TBS/REBA methods (HACKER 2003; POHLANDT & SCHULZE 2008) have been developed from the basic action-regulation theory. *Person-oriented methods* analyse attitudes, coping styles and subjective strain at work. These methods can be combined with observational interviews and task analysis.

2.1 The Task Diagnosis Survey (TDS)

During the last twenty years, a valididated group of instruments, the Task Diagnosis Survey (TDS, in German: *T*ätigkeits*B*ewertungs*S*ystem, TBS) (HACKER et al. 1995;

HACKER 2003) has been developed. The TDS is a semi-standardized system of task analysis, not a questionnaire.

The TDS is an instrument for the objective analysis and evaluation of the complete vs. incomplete structure of jobs. The TDS is intended for the analysis and design of work activities, with the objective of designing job contents in terms of increased effectiveness, optimized mental load, and finally health and personality development.

In terms of health and personality development, it is necessary to check whether narrow task demands will contribute to a loss of qualification, of mental abilities and of physical fitness. Whether the task demands will contribute to a stabilization of skills and abilities, thus compensating for age-related deterioration in elementary cognitive processes, or even whether task demands will stimulate further learning through their learning potential.

Evaluation must be preceded by careful job analysis. The data is gathered by interviewing the personnel – individually or as a group – and observing their work and work environment. The documentation of the enterprise is also utilized.

After background information has been gathered, the structure of the work is studied and the work flow described (work description). The object of work study may be the job of an individual employee, the job-structure of a group or the jobs of an entire department. Jobs are described in terms of work elements or tasks. Once the work flow has been described, the time used for each work element, task, or work phase is noted.

Each task of a job, as well as the job as a whole, receives a profile based on ordinal scales. The scales are grouped into five areas:

A) Organizational and technological conditions determining the completeness vs. incompleteness of work
B) Cooperation and communication
C) Responsibility resulting from tasks
D) Required cognitive operations
E) Qualification and learning potential

2.2 Development of the REBA Predictive Model

In recent years many software tools have been developed in the field of ergonomics, especially for the evaluation and design of physical work (LANDAU et al. 1997). Only a few software-assisted instruments are available in work psychology.

Several validation studies have shown significant correlations between task characteristics and the strain consequences of work. Based on these correlations, an attempt has been made to develop predictive models. Multiple linear regression models were constructed with a data set from 362 jobs. On the basis of the parameters of the model, the probability of negative strain consequences can be estimated from the characteristics of a job. This predictive model is intended to be used for the evaluation of work situations.

The analytic data was collected from different branches. At present, profiles of task demands and mental strain (according ISO EN DIN 10 075) of n= 667 jobs with about 2000 white and blue collar types are available.

Data collection took place at jobs in assembly, machine-maintenance, and control and supervision of technical installations; in call center jobs and service and administrative jobs. Observer objectivity and reliability were assured by using a guide handbook for task analysis and training procedures. This guidance information is also implemented in the software tool REBA 8.1 (in German: Rechnergestützte Bewertung von Arbeitsanforderungen).

REBA evaluates tasks at four levels. The levels *feasibility* and *safety* correspond to the ergonomical job design (LUCZAK 1993). REBA allows one to conduct a rough check as to whether the working conditions guarantee hazard-free execution of the tasks. The ´higher levels´ *avoidance of mental impairments* and *personality developmental potential* are based on the approaches of action-regulation theory (HACKER 2003, HACKER & RICHTER 2006). The scales of these levels, in the software tool, are derived from the TDS.

Statistical analysis has shown that seven task characteristics especially have a significant independent contribution to the prediction of strain consequences. Therefore, in this paper, presentation of the statistical data will be restricted to these features (Table 25.1).

Table 25.1: Relationship between characteristics of job design and short-term strain consequences; beta-weights in multiple linear regressions p < .01... * *, p < .05... *, n = 667 Jobs

Job characteristics	Consequences of mental strain Note for interpretation of the coefficients: low values denote negative strain effects			
	Mental fatigue	Monotony	Mental satiation	Stress
Work task conflicts	.36**	.11*	.23**	.29**
Quality Feedback	.21**		.11**	.17**
Physical variety	.16**	.10**		
Task completeness	.10*	.38**	.29**	.15**
Task cycle repetition			.14**	.10*
Use of qualifications		.26**	.20**	
Learning potential		.10*		
Multiple correlation coefficient R	.49**	.61**	.54**	.40**
Coefficient of determination R^2	.24	.38	.29	.16
Corrected coefficient of determination R^2	.24	.37	.29	.16

For modelling, characteristics of job design were chosen that correlated positively with the effects of mental strain. Ranking of these characteristics higher in the model leads to the avoidance of negative effects. As a design recommendation, this corresponds to the enrichment of job content. For example, if the intention is to avoid predicted monotony using job design, incomplete jobs must first be enriched with tasks of varying levels of demand, the physical variety of routines must be increased, and the use of qualifications and learning potentials must be improved.

In addition to these seven job characteristics, further characteristics were selected for REBA, which, although not used for prediction, allow the user to describe the design of work system almost completely. In total, 22 job characteristics can be analysed with REBA.

3 Application of the Method: Analysis and Evaluation of a Call Center Task Before and After Redesign

3.1 The Scenario

Task analyses of call center agents in both front and back offices were conducted in an in-house call center that dealt with incoming customer enqueries. The objective was to test the suitability of the REBA procedure in the service sector, in addition to assessing the demands and resulting mental workload of the tasks.

The following example describes the task of a front office call center agent.

3.1.1 The Front Office Job Before Redesign

3.1.1.1 Task Description

The front office agents receive inbound telephone calls and predominantly handle information regarding the company's products, registration formalities, as well as invoicing problems. Information could be retrieved by computer via the internal data network. On average, the length of each conversation is 2–3 minutes. 80% of the content of the conversations concerns advice and problem solving, and 20% concerns complaint management.

In addition, invoices are entered into a database at irregular intervals according to need. These tasks are taken over by the back office in cases of work overload.

3.1.1.2 Sub-Tasks with Time Slices

For the purpose of evaluation, necessary actions and tasks were summarized and broken down into percentage of the total working hours (without breaks):

a) Telephoning (inbound)…about 75%

b) Data processing…about 15%
c) Invoice handling…about 10%

3.1.1.3 Assessment Through REBA

The work conditions (feasibility and safety levels) showed various design shortcomings:

- Posture and movement deficiencies, due to tasks being carried out while seated,
- Increased level of noise, due to telephone operation by other agents in the room,
- Unfavourable lighting of the workplace,
- Higher rate of health complaints.

Furthermore, REBA evaluation revealed that due to having a highly limited range of tasks, a lack of feedback, as well as little scope in the task the activity, the front office agents were at a greater risk of mental fatigue. The activity profile on the learning and personality development potential levels showed that there were more deficits than potentials (Fig. 25.1).

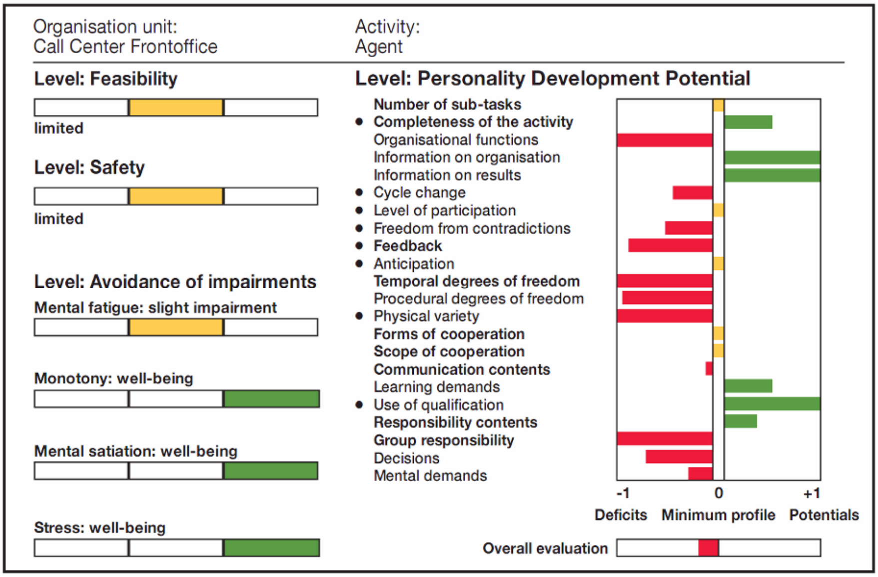

Fig. 25.1: Task profile of front office agent before redesign

3.2 The Participative Design Process

Design workshops were conducted at intervals of approximately 4 weeks over a period of half a year, with 5–8 employees from each of the departments concerned. Great importance was attached to agent participation, as efforts made towards understanding the detailed knowledge of the employees, and any innovative ideas they may have, makes potential changes easier to justify, implement and sustain.

Besides the results of the evaluation, the successes, problems and recommendations for change, concretely identified by employees, formed the basis of consideration and discussion. Employee inputs were structured into appropriate categories and needs for change. This was followed by a search for the causes of deficits. On this basis it was possible to combine general ergonomic and psychological rules with design recommendations by the employees, and to propose solutions.

The results of the individual design workshops were recorded and passed on – with a request for feedback – to employees and managers within the respective departments. Proposals that could be met at short notice were implemented within the framework of the workshops, and long-term schemes were passed on to the respective project teams.

Taking these measures led to the fact that the level of participation by the employees in the company's planning processes was evaluated with excellent results.

3.3 The Front Office After Redesign

3.3.1 Task Description

The critical work conditions (feasibility and safety levels) were redesigned in collaboration with the employees, leading to the following:

- The purchase of cordless headsets, allowing telephoning while both seated and standing. Posture and movement deficiencies were also reduced by fax machine operation (see below).
- Increased noise levels, caused by the agents raising their voices in the room during the course of the shift, being reduced through communication training.
- Each workplace being fitted with additional, individual lighting.

The tasks in the back office (incoming mail handling) were combined to 15–20% with tasks in the front office. In the case of customer queries, all standard letters were handled by the front office agents, without them being passed on to the back office for printing, enveloping, and dispatching. In this way the cycle change, in relation to the overall task and work enrichment, gave the front office agents more scope, content and control over timing. Customer queries were now handled in one place, considerably reducing the processing time of customer orders.

By placing a fax machine in the front office, duplicated work with the back office could be avoided. The task content of the front office agents was enriched and they were granted greater physical variety. Faxes are first seen in the front office and, if need be, dealt with. If the query exceeded the front office field of function, the faxes were passed on to the back office or filed. A rota was fixed, for responsibility over the fax machine. This resulted in higher group responsibility and more communication about organizational issues amongst the agents. Work related communication content and amount was increased and the effectiveness of feedback improved. Previously, feedback to the work group could only be given retroactively, having little effect on the quality of the ensuing orders.

The increase in completeness of tasks led to more mentally demanding requirements, in particular, controlled information processing, i.e., thinking that involves selecting well-known rules, in order to design rule governed work procedures, dominated.

3.3.2 Sub-Tasks with Time Slices

For the purpose of evaluation, necessary actions and tasks were summarized and broken down into percentage of the total working hours (without breaks):

A) Telephoning (inbound)…about 60%
B) Data processing…about 30%
C) Invoices, handling notices of termination, etc…about 10%

3.3.3 Assessment Through REBA and Psychological Questionnaires

Changes in the task profile were seen in the “avoidance of impairment potential” and “personality development potential” levels (Fig. 25.2).

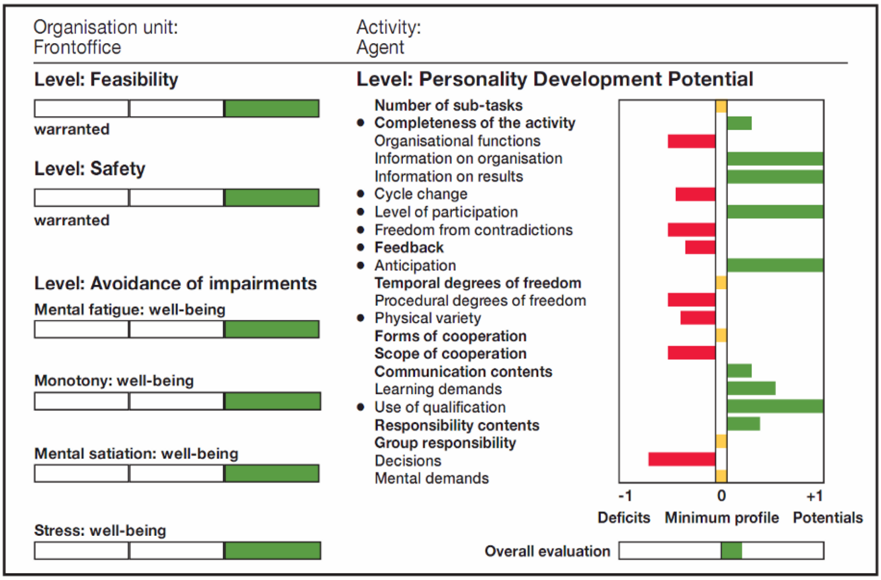

Fig. 25.2: Task profile of front office agent after redesign

The overall evaluation (on a scale of –1 to +1) improved from –.14 to .14. In addition, the change had the effect of lowering the risk of mental fatigue (a negative consequence of mental strain), while the risk of experiencing monotony, mental satiation and stress remained low (Table 25.2).

Table 25.2: Perceived job content and mental health before and six month after the redesign of a front office area in a call center (whole sample n= 38 agents, repeated measures n= 10)

Variables	before redesign		after redesign		significance
	M	SD	M	SD	p
Job demands (FIT)	1.79	.58	2.17	.53	<.10
Decision latitudes (FIT)	2.53	.45	2.68	.36	<.05
Task variety (SALSA)	2.17	.50	2.67	.76	<.10
Underload (SALSA)	3.00	.72	2.67	.72	<.05
Social support (SALSA)	4.13	.80	4.29	.88	<.01
Perceived emotional attacks	2.68	.51	2.15	.71	<.05
Metal health (GHQ-12)	2.39	.15	2.03	.35	<.05
Psychosomatic complaints	1.43	.28	1.57	.48	<.01
Reward (ERI)	2.53	.83	2.87	.63	<.05

M - means
SD - standard deviation
FIT - Richter et al. (2000)
SALSA - Rimann & Udris (1997)
GHQ-12 - Goldberg (1972)
ERI - Siegrist et al. (2004)

The objective enrichment of task quality does not correspond homogenously with the perceived work situation. The tasks have, after the redesign, more the character of "active jobs" (KARASEK & THEORELL 1990). Perceived variety is increased and mental underload decreased. Also social support, especially through superiors, and personal reward are higher.

The reduction in specialization of the front office agents' tasks, through task enrichment, is a better design for this job, because it comprises higher degrees of freedom in respect to content and for timing, as well as having more qualitatively and quantitatively demanding components. But it is necessary to stress that in the same time mental health is reduced and psychosomatic complaints are increased.

Obviously, to cope with the demands of the enriched tasks a higher mental effort is needed, with the risks of reduced mental health. Therefore, an extended occupational safety concept is needed, as a new focus for the implementation of measures for the protection of mental health. The new approach of occupational health psychology can be used to realize such an orientation (SAUTER et al. 1999, RICHTER 2006).

4 Conclusion

The model evaluation and practical applications have shown that a successful psychological improvement of health in industry and administration is possible, with a combination of objective and subjective methods. Such an approach of *salutogenetic job design* should be integrated into the ILO-CORE LABOUR STANDARD (1998). Examples of good practice and evidence for human and efficient job design exist and can be integrated into design strategies and recommendations (PARKER et al. 2001, DEBITZ 2005). Action-oriented evaluation and design instruments can be successfully integrated into the framework of softeware-supported ergonomic approaches (LUCZAK et al. 1996). The software-tool REBA 8.1 is based on simulation models using multiple linear regression models. Therefore, the application is not restricted to the redesign of badly designed jobs, but can be also used as a *prediction methodology* in the early stages of the planning process. In the early phases of the planning process, especially, it is necessary to have a parallel procedure for constructional and technological design, with projective planning of cooperative and/or individual tasks. The process is needed in order to consider the division of functions (human-machine) and the forms of cooperation (e.g. work content, qualification level, work organization) (CLEGG & CORBETT 1997, HACKER 2003).

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ISO 10 075-2 (1996) Ergonomic principles related to mental workload – Part 2: Design principles. Geneve: International Organization for Standardization.

26 How Can Creativity Be Promoted Within the Framework of Vocational Training and Further Education?

Uwe Andreas Michelsen

Before we can say anything about the promotion of creative behavior we need to reflect on the concept of creativity itself.

1 The Concept of Creativity

A classical definition of creativity in terms of the specific difference between the concept itself and a superordinated generic term is not possible. Creativity is a *theoretical construct*, arising from the need to describe the achievements of the human mind by supplementing conventional intelligence tests (vertical or convergent thinking) as a mental resource with tests involving relatively unstructured problems or situations. These problems or situations demand a broad search space and impose few or no practical constraints while at the same time permitting a large number of possible solutions (lateral or divergent thinking).

The definitions of the construct of creativity are manifold. In academic terms, they are partly unproductive and they are frequently not accessible to research, in particular to empirical research. Let me explain by pinpointing three characteristics of the creative process as they are specifically described by creative academics or those who observe them.

- the *suddenness* of a discovery,
- the *unawareness* of how it came about, and
- the *extra-logical path* taken in the process (BROMME & HÖRNBERG 1977).

A first attempt, still worthy of note today, at mapping the trajectory described by creative processes is that of WALLAS (1926). Following POINCARÉ (2003), he distinguishes four successive phases, viz. those of (1) preparation, (2) incubation, (3) illumination and (4) verification.

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(1) Preparation
After a problem has been recognized, its structure is analyzed and the available knowledge is inspected to see whether already known solutions (algorithms) exist which lead to the goal. If the available algorithms cannot be applied, an attempt is made to generate a new solution.
(2) Incubation
In this phase, a flexible approach to available information sets in, enabling information to be related to the matter at hand in new ways. What still remains to be clarified is how the idea leading to the solution emerges from the multitude of arising ideas.
(3) Illumination
The decisive idea, the "trigger" or "spark", comes to the fore. We should remind ourselves at this point of Archimedes and his "Eureka!" At the very moment of settling into his bathtub, the ingenious idea occurred to him of calculating the amount of pure gold contained in an item of jewellery by determining the volume via the amount of water displaced.
(4) Verification
Once the idea is found, it is elaborated so that it can be converted technically or even technologically and applied, for instance, in the form of new products.

The first and fourth phase of our sequence structure ensues consciously: Phases Two and Three are, if only because the processes taking place within them remain uncharted, to be attributed to the subconscious.

Once again it becomes clear that it is not easy to give a definition of creativity that meets the demands of brevity, succinctness and unequivocality. For the time being, we will have to content ourselves with understanding creativity as a hypothetical construct and will have to try to grasp all the facets of what can promote creative behavior as the capacity

- to recognize objects and matters of fact in new relations and in an original way (*originality, re-combination*)
- to use them sensibly in an unusual way (*flexibility*)
- to see new problems where there are apparently none (*sensitivity*)
- to depart from familiar mental schemata and to consider nothing as fixed (*fluidity*), and
- to develop unconventional ideas that deviate from the norm, even against the resistance of our social environment (*nonconformism*)

whenever it is a matter of finding something new that enriches culture and society. Following FACAOARU (1985), I want to narrow things down somewhat by speaking of technical creativity and to equate it with a predominantly creative activity that results in the development of novel or – by comparison with previously existing products – improved products or technical solutions.

2 The Facet Structure of Creativity

Picking up on earlier work by KLUGE and ZYSNO (1988), I am going to postulate that creativity has a facet structure, embracing almost all relevant research approaches and views on the subject. This schema, designed to give us our bearings on the construct of creativity, consists of four facets, namely *problem type, individual, environment* and *product*, which in turn are subdivided into two subfacets. We can distinguish

- a vertical facet – the *problem-product task axis*, and
- a horizontal facet – the *individual-environment resource axis* (Fig. 26.1).

In the concrete solution of a problem all these aspects may possibly interplay and interact.

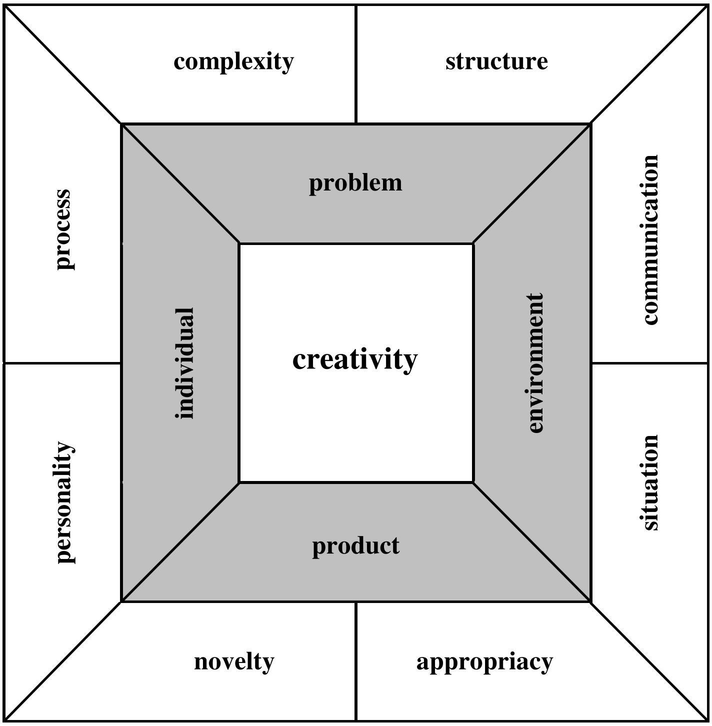

Fig. 26.1: Facets of creativity

2.1 The Problem-Product Task Axis

2.1.1 The Problem

A problem is characterized by

(1) an undesired initial state,
(2) a desired final state,
(3) a barrier that hinders the transformation of the initial into the final state.

Against that, tasks present intellectual demands that can be met with known methods. Tasks demand only reproductive thinking. With problem-solving something new has to be created; problem-solving calls for "creativity" (DÖRNER 1987).

The question is: Which problems demand creativity and which problems call for intelligence? Intelligence is predominantly to be brought to bear where highly structured problems of low complexity are concerned; creativity, where highly complex problems with little structure are involved. Intelligence is thus a necessary but not a sufficient condition for creativity. The more marked the intelligence, the higher the possible level of creativity.

2.1.2 The Product

At the end of any creative work stands a product. No matter whether it is a painting, a scholarly treatise or a technological innovation, chiefly two demands are leveled at a creative product: Novelty and appropriacy, or utility. The criterion of utility rules out products that may be original but are not appropriate to the problem or the situation concerned. Novelty in this context – the context of product creation – means in particular the attempt to find solutions by synthesizing already existing elements and approaches.

2.2 The Individual-Environment Resource Axis

2.2.1 The Individual

The processual components of the feature "individual" can be described following AMABILE (1963) using subject- and creativity-specific knowledge as well as motivational components. According to OERTER (1972), the following personality traits are particularly conducive to creativity:

(1) autonomy in thought and action (nonconformism),
(2) openness to new experiences (maintenance of *curiosity motivation*),
(3) the *verbal expression of internal processes* (emotion, imagination, thought),
(4) *resistance to processes inhibitive of problem-solving* (prevention of stereotyping and of set opinions and habits),
(5) *active processing of conflicts*,

(6) the ability to tolerate problematic and confusing situations and to work indefatigably at their resolution (*ambiguity tolerance, perseverance*).

2.2.2 The Environment

The *situational conditions* are *inter alia* the structure of the workplace and of working hours. For instance, rooms in which the telephone is constantly ringing, in other words where the free flow of thought is continually interrupted, have an inhibitive impact on creativity (the open-plan-office effect). Creativity cannot be "ordained" in terms of time available for its realization. Really creative staff members are driven by their problems outside normal working hours too. Strict regulation of working hours may well even be a hindrance for them. In addition, creativity remains to a large extent invisible to, and is not credited by, management; in individual cases it may not even be desired. Quite apart from the fact is that creative employees occasionally make their superiors anxious and are more difficult to "manage" than their non-creative colleagues or those colleagues who conceal their creativity or who act it out in their spare time. These are aspects that correspond to the element of *communication* in our facet structure. According to TAYLOR (1972), staff members who try to bring creative ideas to bear in the workplace often feel rejected by superiors as well as colleagues. Possible reasons for this might be envy and a reluctance to take risks. Many superiors find it difficult to listen to their staff members and to integrate innovations into their planning. However, groups might well be superior to the individual problem-solver in accumulating knowledge. Various authors (e.g., SCHLICKSUPP 1977, ULRICH 1975, SIKORA 1976) point out that associative links made by group members constitute more than the sum of individual cognitive processes – they also initiate new cognitive processes that go beyond those processes. It is up to those who want to utilize and promote this tendency to create a creativity-friendly group atmosphere, in which according to ROGERS (1962) "psychological security" and "psychological freedom" should prevail. This means that work teams should ideally be emotional "fortresses", also guaranteeing space for thought in the sense that in such groups individual group members can impose the wildest ideas on one another without making fools of themselves. Such mutual trust, however, requires open communication on both the horizontal and the vertical planes, and that throughout the entire company. Let me merely mention that communication in the context of creative behavior also specifically means communication with oneself; in other words, when it is a matter of questioning one's own thought processes. This is true for superiors whose snap judgments in the form of so-called "killer phrases" often have a devastating creativity-inhibiting impact in group sessions. Statements such as: "We've never done that before"; "That won't work"; "We don't have time for that", "Great theory, but what about the practice?"; "Too academic"; "Too modern"; "Which idiot thought that one up?" (taken from CLARK 1971) most certainly stifle any creative impulse.

3 Possible Ways of Promoting Creativity

Ways of promoting creativity result from

(1) systematic training methods that free up creative potential and make it utilizable,
(2) conscious acceptance of behavior peculiar to creative people, and
(3) warding off creativity-inhibiting influences.

3.1 Systematic Training Methods

In an experiment involving three subjects (21 students each, studying Mechanical Engineering, Electrical Engineering and Psychology), KLUGE and ZYSNO (1993) were able to prove on the 95% significance level that trained groups (The groups, which collaborated, were comprised of one student each from Mechanical Engineering, Electrical Engineering and Psychology.) in all tasks requiring techn(olog)ical creativity came up with more innovative and more useful solutions than untrained groups. In the technical problems presented, no difference was detectable, however, between the related "classical" creativity methods of brainstorming and synectics. For company practice in the field this means that *the creative potential of staff members – their ability to establish new links between known items of information – can be enhanced by training*, specifically by using the techniques of brainstorming and synectics.

3.1.1 Brainstorming

The classical method of brainstorming was developed by OSBORN (1963) as a result of the dissatisfaction he experienced with the group meetings in his company, which were rendered ineffective by constant snap judgments on the ideas and by "killer phrases". What he specifically aimed to do was to eliminate evaluations that qualitatively and quantitatively restrict the flow of ideas.

The classical method of brainstorming according to OSBORN (1963) proceeds in the *first phase of idea creation* as follows:

(1) No criticism is allowed.
(2) All ideas are permitted, including "wild" and fantastic ones.
(3) Quantity leads to quality.
(4) The ideas of the participants should be picked up on.

In a second phase, the ideas should be optimized. The following checklist offers suggestions for this process (KLUGE & ZYSNO 1993):

• use differently?	(e.g., in a different context)
• adapt?	(What is so similar?)
• modify?	(What can be changed in terms of shape, color, meaning, motion, sound, etc.?)

- minimize? (Make smaller? What can be left out? Smaller? Shorter? Deeper? Halved? Lighter?)
- substitute? (What can be replaced? Other elements? Other driving force? Other type?)
- rearrange? (Can components be exchanged with one another?)
- reverse? (Can processes be turned around? Positive and negative? Backwards? Upside down?)
- combine? (Can several ideas be integrated into one?)

3.1.2 Synectics

Synectics – derived from the Greek synektikos = cohering, or sticking together – means the fitting together of different, apparently unconnected elements. GORDON (1961), who created this method, analyzed the group session reports of successful invention projects with regard to the mechanisms triggered by the unconscious psychological stages of incubation and illumination:

(1) Playing with words, meanings and definitions

If, for instance, it is a question of solving an inner-city parking problem, a synectics group can first of all deal with the concepts of parking, storing and clearing up in order to establish a general idea of the problem.

(2) Playing with fundamental laws or basic concepts of science

The synectics group imagines, for instance, a universe without the force of gravity, in which water flows uphill.

(3) Playing with analogies

The creative process intended in synectics groups is especially characterized by the fact that the problem-solvers liberate themselves from the customary information links in order to recombine the information in a new and unaccustomed way. Analogy is the form of the link. Analogies facilitate the transference of structures from one subject area, e.g., biology, to another (the human eye – the slatted shutter of a camera).

The synectic process works with two *principles*:

(1) Make what is strange familiar by

a) *analysis*: dissecting the problem complex into its components;
b) *generalization*: identifying those patterns that characterize the components contained;

c) *searching for a model or analogy*: what in one's personal knowledge or personal experience is like or similar to the problem posed?

(2) Make what you know strange by a

a) *direct analogy*:
parachute – dandelion seeds,
house: brick = plant: cell

b) *personal analogy*:
The participants should imagine, for instance, that they are molecules;

c) *fantastic analogy*:
This is not bound to any reality.
Example: Wind is to storm as a single UFO is to the populating of the earth by extraterrestrial beings.

d) *symbolic analogy*:
This consists of the paradoxical relation of a pair of words, comprising an adjective and a noun, with the noun capturing the essential aspect of the personal or fantastic analogy and the corresponding adjective contradicting it or containing a surprise (e.g., intimate openness, simple complexity, a fatal new beginning).

3.2 The Acceptance of Creative Behavior

On account of the above qualities, which typically and demonstrably characterize creative people, it should not be expected that the behavior of these people will be universally accepted in an environment geared to rule-governed order, to "normality". To clarify this, let us recall character traits that are, at least to a fairly great extent, peculiar to creative people.

More than non-creative people

- they tend towards a readiness to take risks,
- they see problems where apparently there are none,
- they verbalize their emotions, imagination and thought processes,
- they endeavor to actively process conflicts,
- they exhibit autonomy in thought and action,
- they develop ideas that depart from the norm, they deviate from accustomed thought patterns,
- they behave in a nonconformist manner.

In a word, creative people may possibly be at variance with the desired image of an "ideal" staff member in the workplace. Those who wish to promote creativity effectively should be aware of these implications and ensure that they themselves and those who work together with them have a minimum degree of acceptance of creative behavior.

Alongside these acceptance problems that are conditioned more by personality structure, we should also take a look at the potentially creativity-inhibiting influences in the sphere of work and vocational training.

3.2.1 Repelling Creativity-Inhibiting Influences

When we recall the environmental influences in our facet structure of creativity (cf. Sect. 1.2), it seems an obvious thing to do to formulate the following theses concerning the repulsion of creativity-inhibiting influences:

- The promotion of creativity must not be postponed until the vocational training and further education stage; it must already be a component of the socialization process.
- The promotion of creativity plays a rather marginal role in the general school system (music and the arts eke out a rather marginal existence as school subjects; the purely repetitive acquisition of knowledge is overrated; there is relatively little promotion of personal initiative and student independence).
- Training in the "dual system" (including the part spent at school), which is organized according to predominantly strict rules of the "order and obey" type, very probably has an inhibiting effect on creativity.
- Our school and training system, including its certification and examination system, almost exclusively promotes and rewards the individual acquisition of knowledge and rote learning; scarcely does teamwork receive such encouragement; independent thinking, self-reliant work habits and problem-solving abilities are not sufficiently credited.
- Ways of promoting creative behavior through the classical methods of brainstorming or synectics, for example, are hardly used in the context of training and further education. They probably do not play the part they could play in the "continuous improvement processes" (CIPs) in large companies and organizations.

Bearing all this in mind, it remains to be said that it is one thing to demand such creativity of staff members, but another matter altogether – which has by no means been exhaustively discussed – to pursue the actual active promotion of creativity.

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Part 5
Workplaces

27 Complexity in Ergonomics

Matthias Göbel

1 Introduction

Complexity is widely seen as an emerging phenomenon of an increasingly engineered and networked society. This obviously includes work life and, hence, ergonomics issues as well. However, the complexity phenomenon seems to be inherent to all ergonomics issues. This again would require consideration of complexity as a fundamental principle for ergonomics.

Before discussing this matter further, we need to clarify what the term "complexity" means. It has its root in the original Latin word "complexus" which signifies "entwined" or "twisted together". A complex is thus a set of two or more joined components that are difficult to separate because of their interaction. As a consequence the components of a complex cannot be separated without destroying the entity (HEYLIGHEN 1997). One would consider a system more complex if more parts and connections (relationships) are involved.

Complexity is thus neither complete disorder (because of the ordered structure and, in principle, reliable reaction) nor complete order (that would allow description using traditional deterministic methods). This situation "at the edge of order and chaos" (WALDROP 1992) explains why complexity has turned out to be very difficult to define and all the definitions that have been proposed fall short in one respect or another.

Stating that complexity is no complete disorder, one should ideally be able to describe a complex system by a sufficiently large number of variables. However, as a decomposition into separate subsystems (expressed by linked polynomials) is not feasible (this would be the case only for complicated systems), an empirical analysis of a complex system is likely to be impractical due to the large number of cases and conditions to be studied and due to the initial value problem of systems with memory effect (feedback). This accounts for the frequent connotation of complexity with "difficult". Depending on its characteristics and the conditions of operation, a complex system can be approximately characterised by simplifying rules on a larger scale, or show unexpected reactions.

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Coming back to the ergonomics context (see Fig. 1 of the editorial), it sounds comprehensive to classify work systems on a rather macroscopic level as complex. This is due to the large number of social instances involved and due to the inner complexity of any role playing instance in work life.

However, the complexity attribute is also valid at lower, rather microscopic levels. This is due to the fact that any conscious human reaction is bi-directionally linked to an individual learning process: Any movement is affected by previous motor learning, as well as by the whole cascade of individual and social experiences. Furthermore, any voluntary reaction or execution of a movement affects the individual's experience on an endogenous and an exogenous level. Those constituents of our personality validate the complexity attribute of any system that involves actively performing humans.

Some further characteristics underpin the complex behaviour of a work system involving humans, for example:

- Reaction delays immanent to humans, ranging from milli-seconds (reflex arc) to decades (ageing, occupational diseases);
- Non-monotonous performance characteristics of humans that follow an inverted U-characteristics for most parameters;
- Different response characteristics of humans to superimposed stresses (Luczak 1982);
- Individual interests affect human behaviour and, hence, task execution.

Widening the scope, one might ask the question what implications the complexity attribute has on theory and application of ergonomics.

First, it complicates or even disables a consistent analysis, and, as a consequence, establishment of a thorough ergonomics theory. Apart from the fact that ergonomics is multidisciplinary in nature and, thus, makes use of a widespread range of methods and approaches, the conceptual and methodological base of ergonomics is still very fragmented and most models are incompatible to each other in the sense that they cannot be applied with a consistent dataset or they do not deliver a consistent output. This is not due to a failure of ergonomics researchers ("if we cannot develop general laws we are not scientists and may as well go out of business", MEISTER 1995 in WILSON 2000) but an inherent consequence of the complexity argument: As a work system is complex, one can indeed separate the different parts of it but one may not dissolve all the effective interactions. One would have to study each system on its own, and still face the challenge of its complex behaviour.

The only practical option of a simplified consideration has the consequence that it is incomplete in terms of scientific reasoning and thus needs the introduction of additional expertise to estimate those aspects which may have an impact but were not covered by scientific reasoning.

This again has important consequences, amongst others, on:

- ethics: how can the consideration of human needs be assured and how can equity in treatment of human rights be guaranteed (LUCZAK 1997b)?

- application of ergonomics: how to develop reliable methods that deliver similar results independent from the conducting ergonomist and her/his methodological estimates?
- design: how to develop design outcomes on incomplete (explicit or implicit) models of a work system or a human-machine system? How to minimise the following trial-and-error cycles in the development process?

Such considerations motivated different authors (e.g. MORAY 1994, MEISTER 2000, WILSON 2000) to argue whether ergonomics is a science or an art. According to the aforementioned considerations it has to be both at the same time, and this again is a conceptual challenge.

2 Dealing with Complexity in Ergonomics

On a practical level complexity can only be mastered by simplification or reduction to what factors of the complex system can be controlled. However, one must not consider all other factors as non-existent (although this is a very human reaction), because they will have an effect whether or not they can be accessed.

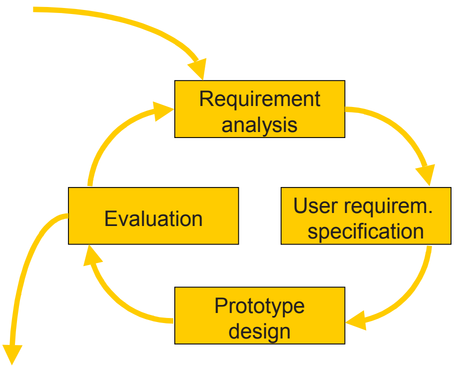

Fig. 27.1: User centred design process according to EN ISO 13407

Projects dealing with complex issues are thus mostly structured as iterative feedback circles (Fig. 27.1). This allows introduction of expertise and correction of results if it turns out that they do not fulfil the expectations. However, such a strategy might be very time-consuming and costly if numerous iteration cycles are required, and yet its end is hardly predictable. This is particularly the case for ergonomics applications that do not allow progression from a general to a detailed level due to their complexity. BOENISCH et al. (2004) for example described the design process for an anaesthetics machine using 15 iteration cycles just for the conceptual level.

For real work systems the practical problem arises that any (test-wise) implementation in the real work system requires an extensive change management process, and, having humans in the role of “guinea pigs” during iteration cycles, may raise ethical concerns. On a conceptual level real work systems do have to consider management activities in addition to straightforward execution processes. This extends the scope of design: regulation options might be considered during design or they might be assigned to the managers for handling within the work system. In both extreme cases such a work system would be either strictly organised or it would only assign authorities and leave all procedural planning to the managers.

Coming back to the complexity problem, what are the methodological requirements that support ergonomists? In an ideal case one would look for a consistent ergonomics model that dissolves the complexity problem (LUCZAK et al. 1986, SINCLAIR 2007). Realising that this is not feasible to date, an approach to qualitatively integrate as many aspects of complexity as possible would however help to manage the complexity problem by explaining its phenomena. Because of the structural link this encompasses the analysis problem and, consequently, the design problem as well (“general” and “developmental” ergonomics according to MEISTER 2000).

3 Ergonomics Extensions to the System Theory

The following paragraphs discuss some suggestions on how to expand the system theory to allow further consideration of human characteristics, to explain complex system responses and to structure the design process. Although those different modules (or fragments) mostly relate to well-known phenomena it is the purpose of this setting to enable an unrestricted combination of all principles. Due to space limitations only a selection of principles is discussed here.

3.1 Five Dimensions to Define a Work System

The description as a work system (Fig. 27.2) is an elementary (object based) approach. In a more general form human and technical system elements are displayed as basic elements of a socio-technical system (PASMORE 1988, ZINK 1997, ULICH 1994) or as an extended framework for humans, technology and organization in interaction (EKLUND 2003).

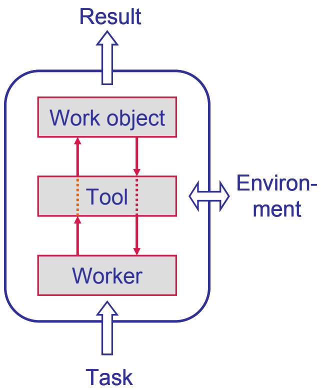

Fig. 27.2: Work system model (according to LUCZAK 1997a, p. 13)

A work system consists of elements and relationships. If a physical representation is assumed, elements can be identified as objects while relationships are interactions (effects and reactions). Furthermore, the localization (spatial representation) of the objects as well as the sequence (time representation) has to be considered. Interactions result in the change of the state of the interacting system elements.

Therefore, at least five dimensions are necessary for a comprehensive description of a work system:

- Elements (structures, resources, etc.)
- Interactions (tasks, actions, processes, etc.)
- States (aims, results, effects, etc.)
- Sequences (order, time, etc.)
- Localization (position, orientation, etc.)

Each dimension is represented by a number of factors or parameters. The dimensions mentioned are relevant for the planning as well as for the execution of tasks. Common models and representations mostly contain two to three of the dimensions mentioned, e.g.

- Flow charts: interactions & sequences,
- Technical drawings: elements & location,
- Block diagrams: elements & interactions.

This simplification enables an overview. A representation containing five dimensions each with several parameters cannot be displayed easily. However, the reduction of a smaller number of dimensions assumes independence from the other (not displayed) dimensions and therefore must have a limited scope of validity for which independence can be assumed for a larger extend.

3.2 Representation as an Open Hierarchical System

Work systems have to be considered as open systems as they are subsystems of a wider system company and society context (EMERY 1959). In order to allow a description of such a system without being able to describe the whole system (as it is required for open systems) a hierarchical structure using similar techniques for all hierarchical levels, thus a recursive (fractal) system concept is required.

Hierarchically structuring systems for ergonomics were, among others, proposed by LUCZAK et al. (1986), GREY et al. (1987) and, considering the different level of regulations of human actions, by OESTERREICH (1984).

3.3 State Variation of System Elements

Interactions (relations between system elements) result in changes of the state of involved system elements via reflexive feedback. Beside feedback that is caused directly by the interaction (e.g. change of position of tool and hand during a task), additional changes of the state may occur in the form of indirect changes like side effects or resulting structural changes (e.g. muscular fatigue while holding the tool). Typically, these are effects of strain or fatigue, as well as changes in the activity level, training or learning.

Furthermore, changes of state due to interaction with the environment have to be considered (e.g. heat radiation). Such state variations are explicitly important as they may influence the behaviour of system elements on the level of:

- Performance characteristics and mode of task execution (e.g. changing of the body posture of the operator due to muscular fatigue),
- Action planning, in terms of the anticipation of changed performance characteristics (e.g. scheduling of rest brakes or job rotation), or
- State of hierarchically higher system elements (e.g. impact on work group or division).

In addition, for work design it has to be considered that indirect changes of system element states normally occur with time delay. This can last from minutes to years (e.g. motor skills, impairment due to long-term exposure).

3.4 Behavioral Characteristics of System Elements

A system element can behave in three different ways (see Fig. 27.3)

- schematically (independent of the element state),
- algorithmically (dependent on state or conditions), or
- as active problem solver (generation of new solutions).

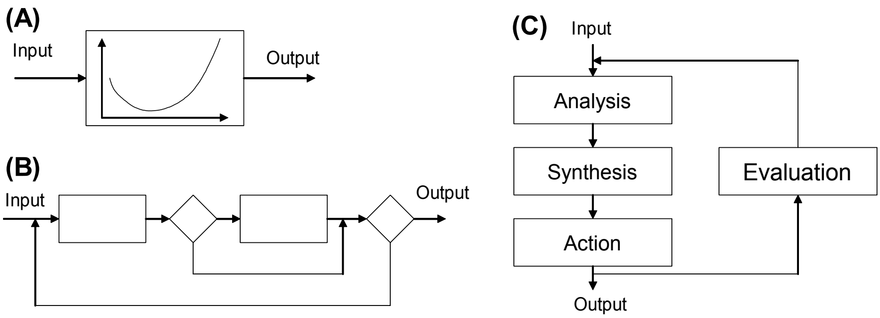

Fig. 27.3: Characteristics of system element behaviour: (A) schematic, (B) algorithmic, (C) problem solving

Schematic behaviour (independent of the element state) causes a constant relation between input and output of the elements, as e.g. in a muscle. Typically, this can be characterized by a response curve or a field of response curves. Algorithmic behaviour (dependent on the element state) is characterized by a variable relationship between input and output. The relationship varies depending on one or more internal or external measure or element states. Behaviour like this is typical for the application of checklists or the work of software programs.

A system element that behaves in a problem solving manner is able to actively generate (new) solutions. A relationship between input and output exists only due to the fact that the element generates an output that results in a change of the system element state of the work object in a way that corresponds to the set task as perfectly as possible. Generally, in work systems in which the task leaves structural options, i.e. in which the task execution is not completely determined, at least one problem solving element is necessary to transform the task into actions with the objective of fulfilling the task.

Problem solving behaviour is associated mostly with human behaviour; however all three types of characteristics can be represented by human as well as by technical system elements. Human behaviour can be restricted to schematic or algorithmic behaviour by corresponding task instructions, and the relative task complexity can be reduced with experience or training by incorporating algorithmic or schematic behaviour strategies (RASMUSSEN 1976, HUNT & ROUSE 1984, ROUSE 1981).

Available time does not play a role for schematic and algorithmic behaviour (as long as time allocation does allow for the task to be processed), but may have a crucial impact on the output of problem solving (WICKENS 1984, HOLLNAGEL 2002).

The differentiation of the three types corresponds approximately with the cognitive types of task suggested by RASMUSSEN (1986), as well as the lower levels of goal-directed action concepts (HACKER 1986, OESTERREICH 1984), although the differentiation here is motivated differently.

While schematic and algorithmic behaviour can be described and therefore anticipated, problem solving behaviour always contains a creative process to generate a solution iteratively by comparison of actual and desired state.

3.5 Memorization in Problem-Solving System Elements

Problem solving consists of a creative process to generate a solution referring to stored information (memory), as well as at least one feedback loop. Each step of the problem solving cycle requires referring to the stored information with respect to categorizing observations, assessing solutions and anticipating system changes (see Fig. 27.4). The content of the storage determines the type of solution (and as a consequence the quality of the solution), as analysis, synthesis and action refer to the stored information and therefore each assessment of success is based only on this stored information. This happens in the sense of anticipation (LUCZAK 1995), using experience to estimate the consequences of a theoretical option and, when putting into reality, filling the memory by experiences from real world. A different memory would result in different actions and in different assessment of actions.

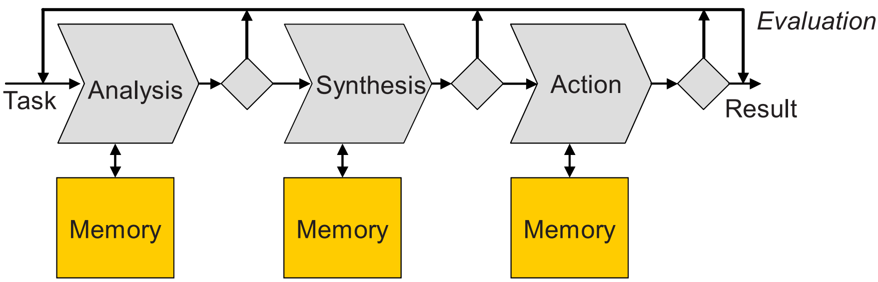

Fig. 27.4: Reference to memory in the problem solving cycle (rhombus = decision)

This is true for a current situation of action as well as for the assessment of a fictive design solution. The importance of the memory is linked to the feedback and enables expertise to be built up by comparing the current situation with former situations and developments. Technically the memory can also be extended by increasing the number of people involved (e.g. through participatory approaches, NORO & IMADA 1991). However, the more expertise is available the more difficult it may become decision making.

3.6 Integration of Different Objectives

Beside the objective of fulfilling the task for the task execution as well as the preceding action planning, ancillary conditions (e.g. availability of resources) and optimization criteria (e.g. with respect to the consumption of resources) have to be considered (Fig. 27.5). This means that the input for the planning element consists of the task, information of relevant states of other system elements as well as individual needs (KAHNEMAN 1973, SANDERS 1983, WICKENS 1984).

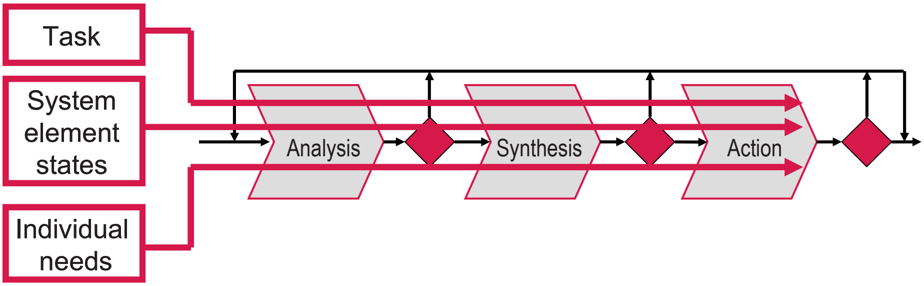

Fig. 27.5: Balance between task-related, resource-related (system element states) and individual objectives (rhombus = decision)

For the development of action strategies task-related, resource-related and individual objectives therefore have to be balanced. This arises for example with humans. In this case the different objectives cannot be expressed using a uniform scale and, hence, they may not be weighed up rationally (see SMITH & SAINFORT 1989, CARAYON & SMITH 1993).

In fact, many more factors have to be balanced, such as short-term and long-term effects as well as efficiency of the effect and the risk of being unsuccessful. Additionally, the planning of action has to ensure the feasibility in principle on the lower hierarchical levels as well as the conformity with the higher hierarchical levels that can normally not be actively affected.

4 Integration of the Different Approaches: Parallel and Hierarchical Cascades Problem Solving

The proposed approaches are not new in principle. However, expressing them within the formal frame of systems theory this allows any combination of the different approaches. This, again, builds the basis to reflect complex system behaviour. This is demonstrated in the connection of problem solving system elements in a parallel or hierarchical (cascaded) order.

4.1 Parallel Problem Solving

Parallel connected problem solving occurs if different problem solving instances work concurrently for a task (Fig. 27.6).

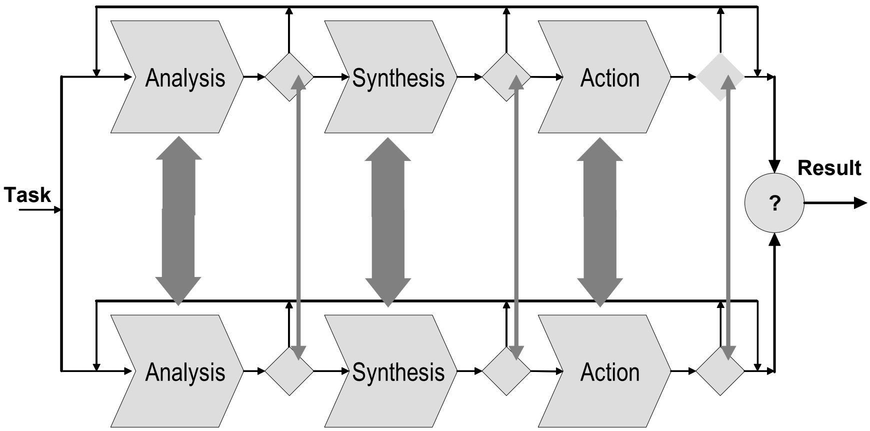

Fig. 27.6: Principle of parallel problem solving

This approach makes sense for example to achieve a reduction of time to find any (practical) solution (e.g. trying to decode encrypted information). In this case the problem solving elements process the task independently. The objective is attained if one of the problem solving elements has found a solution.

In another case the problem solving elements may work together for a joint solution of optimised quality. This is represented as well in form of parallel problem solving, but requires synchronizing of all decision makings in order to avoid inconsistent procedures in the following. Thereby all information would have simultaneously to be made explicit for consistent cooperation. If such an information exchange is feasible only to a limited extend (what is most likely for problem solving units, particularly with human elements), a non perfect cooperation has to be accepted as a matter of fact. This type of cooperation is also a challenge for parallel acting human and machine operators.

The potential benefit of parallel problem solving consists, on the one hand, in a greater number of factors to be considered and, on the other hand, in the opportunity of incorporating more experience. The risks of parallel problem solving in contrast is the high effort necessary for coordination as divergent behaviour of the problem solving elements may result in actions of alternating compensation (one problem solving element tries to compensate the action of the other and vice versa).

4.2 Hierarchically Cascaded Problem Solving

Hierarchical structuring of subsystems presents itself as cascading. A hierarchical structure is easy to represent as long as the lower level contains elements with schematic or algorithmic behaviour. If a subsystem contains one or more element(s) with problem solving characteristics the behaviour of the subsystem is not explicitly predictable, but can only be described as strategy of problem solving behaviour (Fig. 27.7). From the point of view of the higher level of hierarchy it is not the actions that have to be coordinated but rather the tasks and framing conditions.

This can be depicted for supervisory tasks of self-dependent individuals with more or less extensive degree of freedom for action. This type of supervisory task can be anticipated much less than the supervision of algorithmic or schematic acting system elements. However, the task of a problem solving (sub-)element is much more flexible with respect to changes of the task, internal ancillary conditions or internal structure. This effect can be observed in semi-autonomous workgroups in combination with parallel problem solving (HENDRICK 1997).

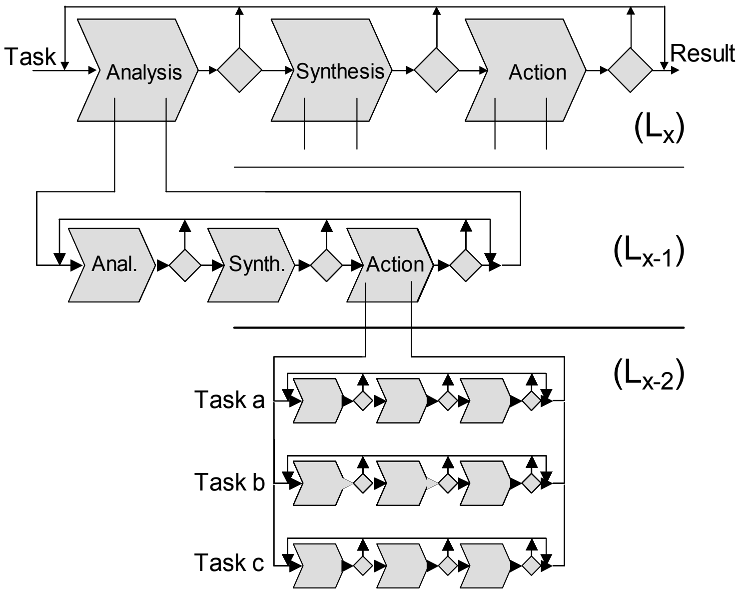

Fig. 27.7: Principle of hierarchically cascaded problem solving (L_x = top level, L_x-1=second level, L_x-2=third level)

5 Work Design as a Problem Solving Task

The fact that the systematic procedure and the system model use the same structure allows joint application for the work process and the design process ("micro logic" and "macro logic" according to HABERFELLNER et al. 1997).

The task of work system design can be represented as a problem solving cycle. The work system can be designed to behave schematically, algorithmically or as a problem solver. The behavioural characteristic of the work system that has to be designed depends on the structure and the degree of freedom allowed for the individuals. The challenge of work system design therefore is not only the system analysis and the understanding of the system to be designed, but also the anticipation of the system element's behaviour (in this case the behaviour of the individuals working in the work system that has to be designed, LUCZAK 1995). Therefore, the task of system design can be described as cascaded problem solving on a higher hierarchical level and the work system of the lower hierarchical level (or lower levels; Fig. 27.8). From this perspective the structure of the design process is identical to the structure of a supervisory task. Notwithstanding, the system variables for system designers and supervisors differ in detail. While the system designer primarily designs structures and resources (which determine the processes for the user or actors in the system), supervisory tasks concentrate primarily on strategies and processes in the context of structures and resources defined beforehand.

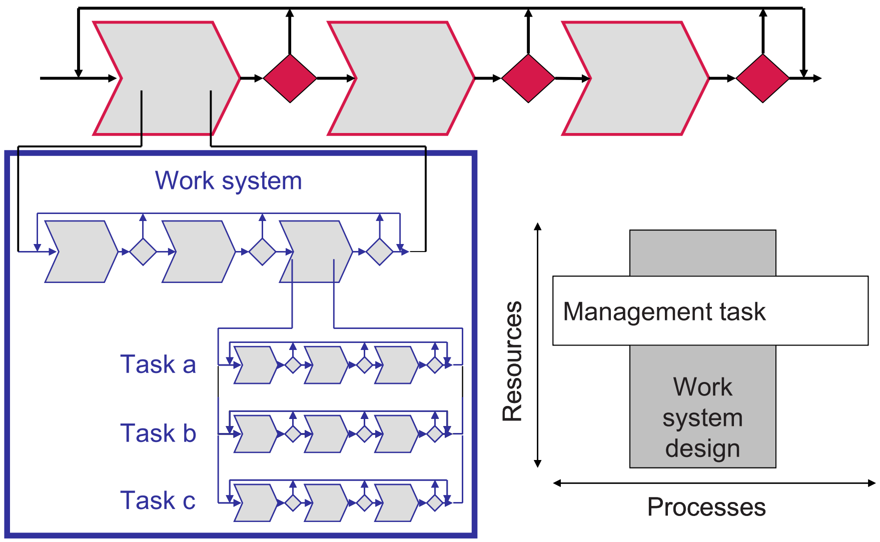

Fig. 27.8: System design as problem solving on a hierarchical higher level

One not only has to consider the complexity of the different tasks and situations but also all tasks and constellations of the work system in a design solution. However, this may result neither in the fact that dealing with complexity is passed through to the actors nor by reduction of the degree of freedom of the actor to a limit that the designer can deal with.

Dealing with complexity therefore needs balancing, as on the one hand, the complexity for the system designer has to be confined on a level that can be controlled and, on the other hand, not to destroy the internal mechanisms of self-regulation which may result in a limited ability of the system to react on external changes.

However, it has to be considered that the design of degrees of freedom is an elementary ergonomics requirement (e.g. ULICH 1994). Thus, work system design that reduces the behaviour of the individuals to an algorithmic characteristic is not appropriate for this reason.

Another challenge for the design of work systems results from the fact that not only task related objectives have to be considered but also resource-related and individual objectives.

6 Conclusion

As a hierarchically structured recursive approach the concept may be applied similarly for micro-ergonomic issues as well as for macro-ergonomics. Different detailed concepts and modelling approaches may be included qualitatively according to specific needs.

Using the work system model, the design of work systems appears as a cascaded problem solving task with the design process one hierarchical level above the work system. Thus, the design task is structurally similar to executive functions. In detail, differences exist in a way that the design of the production system mainly controls resources considering possible variations of tasks and conditions whereas the operative management of the production system mainly concentrates on processes and assignment of (available) resources within a limited time budget. Due to the larger variances design tasks mostly appear more complex than management tasks.

Thus, the complexity of a work system is challenging, not only for work analysis and design, but also for the responsible actors within the system. Coping with the complexity of a system requires additional resources (mental effort, time), and high complexity may exceed the capacity of the actors to shape action strategies within a limited period of time. The restricted information processing capability of humans may require a reduction of complexity in order to avoid failure due to overload caused by system complexity (depending on individual expertise). Strategies of the actors to reduce complexity thus have to be considered for system behaviour (HOLLNAGEL 2002). This is of particular importance when considering multiple workers acting with different degrees of experience in parallel (representing parallel problem solving units), as well as operators having different ranges of decision and control (representing hierarchically cascaded problem solving units).

Dealing with system complexity thus requires balancing complexity between system designers and actors. Furthermore, system complexity has to be balanced in way that it does not exceed the coping capacity of designers and actors on the one hand, nor must not be reduced to restrict system reaction and adaptation capabilities.

Considering the value of such theoretical considerations one might argue that this has little practical value because it is abstract to apply and, furthermore, does not provide quantitative output as pure engineering models would do. However, although there are numerous limitations to consider (and ever will be as long as the system is of a complex nature), such a type of modelling might be helpful to integrate and to structure different relevant Human factors approaches. Further it enables to transfer this model into a compatible work system design frame, providing anticipatory explanation of many side effects (that occur in any system that involves humans).

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Standards

EN ISO 13407, 1997. Benutzer-orientierte Gestaltung interaktiver Systeme. CEN, Brüssel.

28 Principles, Methods and Examples of Ergonomics Research and Work Design

Helmut Strasser

1 Introduction

The graphic term "ergonomics" as a combination of the Greek *ergon*, (1 Erg was the former term for work) and *nomos* (the Greek term for order or fundamental science) translated freely, has to do with the more bland *work science*, a science which is expected to contribute to the design of user-friendly products and working conditions which are adequate for human beings. Ergonomics or the more precise anglo-american term "Human Factors Engineering" makes clear that fundamental knowledge about the functioning of the human body, i.e. the most complex system on earth, is indispensable for activities in this field. In this context, the definition of Ergonomics according to IEA, the International Ergonomics Association shows the way and the objectives of a scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theoretical principles, data, and methods to design in order to optimize human well-being and overall system performance.

2 Systems-Oriented Perspective of Ergonomics

In Europe, two terms become more and more popular, i.e. "Product Ergonomics" (BUBB 2003) and "Production Ergonomics" (STRASSER 2003a), referring to the activities of ergonomics at user-friendly design of products on the one hand, and the design of humane working conditions during the production process on the other hand. The also often used terms "Macro" and "Micro Ergonomics" may make clear that the macroscopic view, on the one hand, deals with the optimization of the relationships in the system "Man – Technology – Organization". On the other hand, Micro Ergonomics in a systems-ergonomic view focuses on the optimization of the interaction between the human body and the computer or a machine (Fig. 28.1).

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In any work system the human being, at least to some extent, functions as a controller as visualized in Fig. 28.3 in an abstract cybernetic depiction. Similar to a computer consisting of a power supply and a central processing unit with various interfaces, the operator with his physical capacities controlled by the central nervous system communicates via his sensory and motoric system with the outer world.

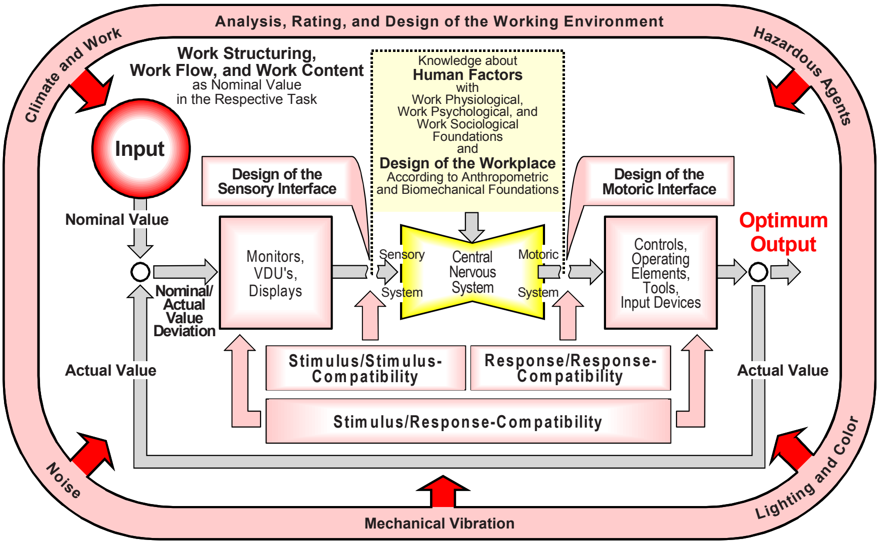

Fig. 28.1: Depiction of the main tasks of Micro Ergonomics by fitting the adaptable technical system elements of the working conditions to the properties of man acting as a controller in a man-machine system

He receives information regarding the work's task as a nominal value, as an input, either via direct observation of the work flow or via monitors, VDUs, and displays. Then, in turn, the human being influences control elements, tools, and input devices via the body's motor skills. An optimal output in the control loop "work" can, of course, only be achieved if the technical-organizational design elements are adjusted to the human capabilities and physical limits. That is, humane workplace design must follow the guideline that the human body is the ultimate standard.

If knowledge about the human factors with work physiological, work psychological, and work sociological foundations is applied appropriately, i.e. workplaces are designed according to the anthropometric and biomechanic foundations and the human operator is not perceived as a time-invariant technical servo element but performance modulating factors are regarded in work design such as motivation, learning and unavoidable fatigue and circadiane rhythms, then substantial requirements for overall system performance are fulfilled. Furthermore, very specifically, ergonomic work tool design has to be utilized in the sensory interface and in the motoric interface. That means response-response-compatible control elements and tools have to be planned according to the guideline that "what is appropriate for the human body is also appropriate for the human hand"; On the other hand, according to the laws of the stimulus-stimulus compatibility, the natural presentation of information and artificial displays have to be coordinated optimally by an extensive agreement between reality and its image. Also a high degree of stimulus-response compatibility, with clearly recognizable and unequivocal stimulus-reaction relationships, with cause and effect connected in the simplest possible way has to be implemented. Finally, in the world of real work, influences of the work environment will almost always play a role. It is one of the fundamental tasks of ergonomics to analyze and rate the complexes "climate and work," "light and color in the workplace," the impacts of mechanical vibrations and noise as well as hazardous agents and to make a proper (i.e., with humane measuring systems) judgment in order to develop, as necessary, concrete protective measures for the human body. Climate and work must be coordinated with each other so that the human body as a chemo-dynamic "power plant" with substantial heat production dependent on physical activities does not overheat. On the other hand, rather high physical activities sometimes have to be demanded in order to compensate heat loss in a cold environment. Acoustic stress from noise at the workplace but also from music, must be limited, so that affected persons do not loose their hearing for good and in order to avoid annoyance and detrimental effects on acoustic communication. Lighting and color schemes in the workplace and displays, i.e., information providing tools must be designed to allow the eye – as the primary sensory organ – to process the wealth of information in a not too time consuming way.

All the topics addressed in the control loop "work" in Fig. 28.1 and shortly described above, primarily, are of significant importance for the ergonomics education. But they also have to be kept in mind for comprehensive ergonomics research approaches which can be divided into field and laboratory investigations. For comprehensive work analysis and ergonomic design of working conditions see especially the monograph edited by LUCZAK and VOLPERT (1996).

3 Procedures of Applied Ergonomics Field Research

Humane work design as preventative work safety typically requires a comprehensive analysis and problem-adequate assessment of the working conditions in industry, in the office or in the service sector. A valid and reliable assessment of the mostly undefined actual working conditions deemed worthy of improvement is absolutely necessary for ergonomics intervention measures, just like a doctor's correct diagnosis is a necessary prerequisite for the treatment of a patient. Therefore, a comprehensive analysis of real-life working conditions requires the utilization of multi-dimensional research approaches in field studies, whereby due to the physiological and psychological human characteristics as well as social needs an interdisciplinary character of ergonomics must be taken into account.

The multi-dimensional ergonomics approach of recording workload via simultaneous analyses during the working shift is shown in Fig. 28.2. In the following it will be described in detail and explained by examples from ergonomic studies in self service shops. According to the central part of Fig. 28.2, it is absolutely necessary to analyze the spatial workplace conditions under anthropometric or ergonomic aspects. In this respect, e.g., it is important to check whether the interior dimensions of a workplace layout are based on the tallest potential worker. The sideview of a cash register work station with a male 95th percentile stencil (Fig. 28.3) can show whether important anthropometric dimensions and actual values in comparison with nominal values and recommendations for cash register work stations, such as height of the leg space under the till shelf A and under the conveyor belt B or a suitably adjustable seat height C are provided. Similar is true for the depth of the leg space at knee and foot level F and G.

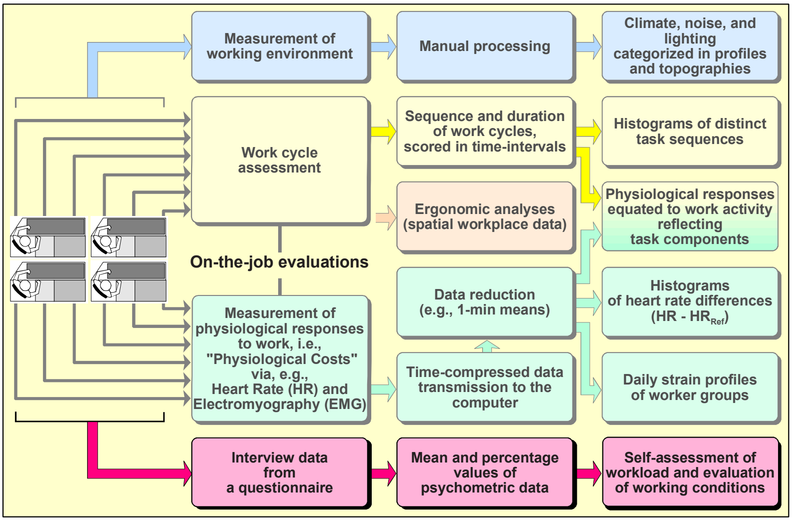

Fig. 28.2: Multi-dimensional recording of workload via simultaneous analyses during working shifts **(**STRASSER 2003b**)**

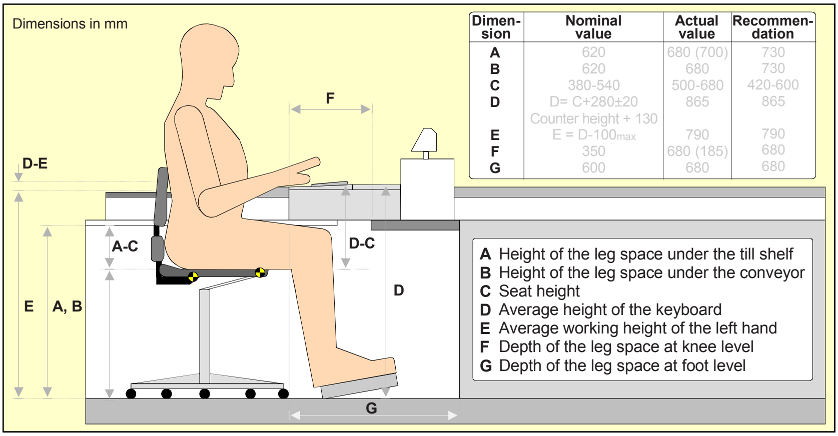

Fig. 28.3: Side view of the cash register work station with a male 95th percentile stencil and important anthropometric dimensions and actual values of the cash register work station

Work course analyses, i.e. work cycle assessments (cp. second row from the top of Fig. 28.2) which document what is done by workers, in which order and when and how it is done, are also an important and wide-spread topic for the assessment. The results have to be documented in histograms of distinct task sequences. Sequences and duration of distinct work cycles, scored in time-intervals can also be used to extract physiological responses equated to work activity reflecting task components provided that also work-physiological measurements have been carried out.

Traditionally, in ergonomics also measurements of the physical working environment (see upper row of Fig. 28.2) have to be made, and the results have to be documented in topographies and profiles of climate, noise and lighting data. It may be mentioned that these data do not necessarily reveal the ultimate effects on the human body, since they represent only data of stress and do not reflect strain, i.e. physiological responses (cp. the chapter on laboratory research). However, to be able to recognize, measure, and cope with the presence of adverse physical or chemical conditions in order to protect the employees from work-related illnesses or, possibly, even occupational diseases, they are, no doubt, absolutely necessary. Just in order to give an example, it will always be helpful to determine and report the dry-bulb and wet-bulb temperature (i.e., the relative humidity) and air velocity, measured at different times and different potential workplaces – in the checkout area or in the rest of the store – in addition to climate summary measures such as the NET (Normal Effective Temperature). This is also true for the lighting conditions, in order to be able to check compliance with legal work safety rules and regulations.

Illuminances at 6 locations (Fig. 28.4) in a self service shop at 4 preselected times, i.e. at 9.30 am, 12.50, 3.00, and 5.30 pm can represent the actual lighting conditions of a typical workday which in this case are favorable and exceed the required minimum of 300 Lux in the shop and 500 Lux in the checkout area.

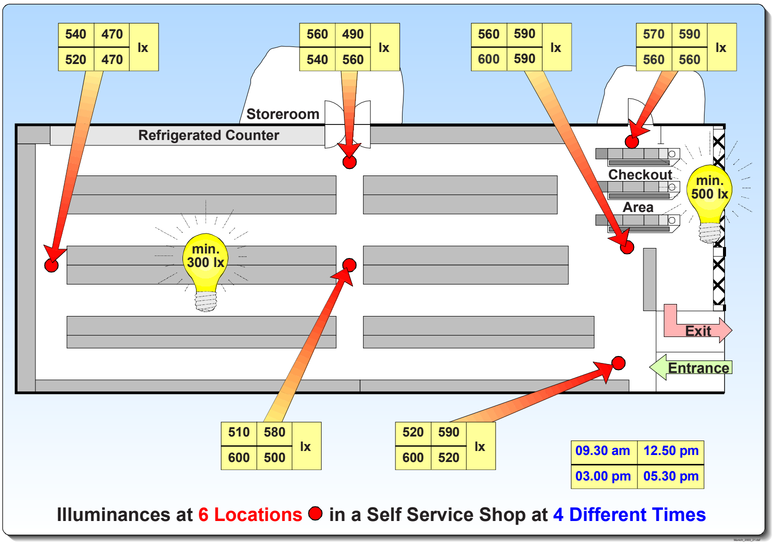

Fig. 28.4: Results of measurements of the lighting environment (illuminance) in a self service shop (KLUTH et al. 2002)

Ultimately, a truly humane ergonomic analysis will always be based on the actual strain on the workers caused by their job. Work-physiological approaches are indispensable, e.g., in order to quantify physiological costs, i.e., how much ("blood and tears") the various organ systems must "pay" for a demanding task which has to be carried out.

Techniques which are sensitive to and reflect the various body activities involved in the tasks must be used for this approach. As shown in the lower part of Fig. 28.2 the subject-related strain of the employees may become obvious in physiological responses such as heart rate or electromyographic activities during on-the-job measurements. It goes without saying that these measurements go beyond snapshots. Instead, measurements during longer time periods or an entire shift must create a valid and reliable depiction of the effects of work on the human body. To that end, multi-channel electromyographic measurements of the involvement of the musculature of the hand-arm system are typically required.

Myoelectric signals from muscles involved in work, however, need a very detailed multi-channel recording and evaluation procedure so that they can be interpreted in terms of strain. As shown in Fig. 28.5, this comprises smoothing by software, standardization, i.e. relation of the actual EA to the maximum electromyographic activity, EA_{max}, arising under maximum voluntary contractions of a muscle, and also splitting up standardized electromyographic activity (sEA) into static and dynamic components which can reflect ergonomically relevant parts of muscle strain.

On the other hand, recording and evaluating heart rate as a classical work-physiological parameter is quite simple. The continued heart rate monitoring of 4 shop-assistants over 120 min of uninterrupted cash register work as an another

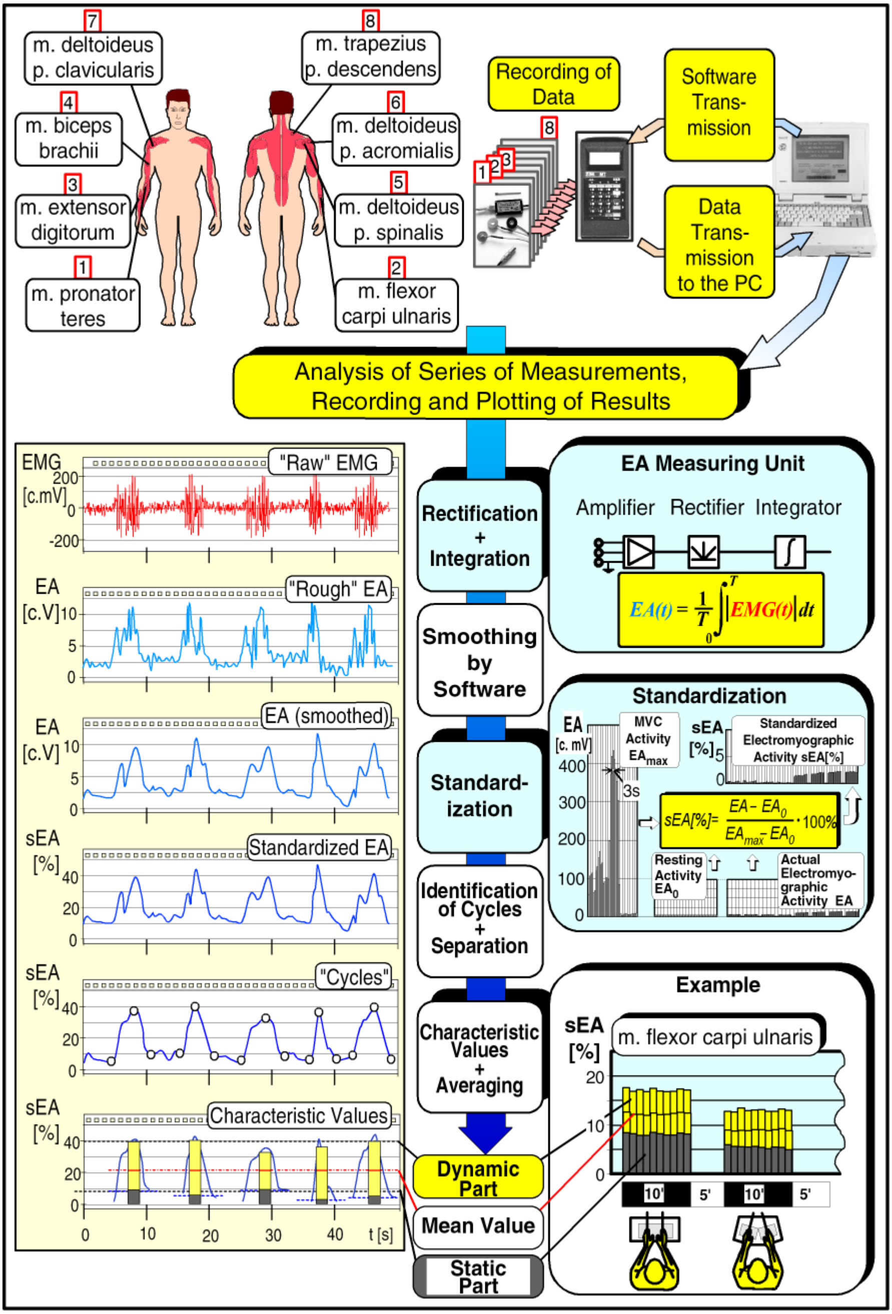

Fig. 28.5: Schematic representation of the recording and processing of electromyographic data (STRASSER 2006, STRASSER et al. 2007)

example for recording physiological responses to work (Fig. 28.6) reveals that work at the cash register does not seem to be problematic for the cardiovascular system.

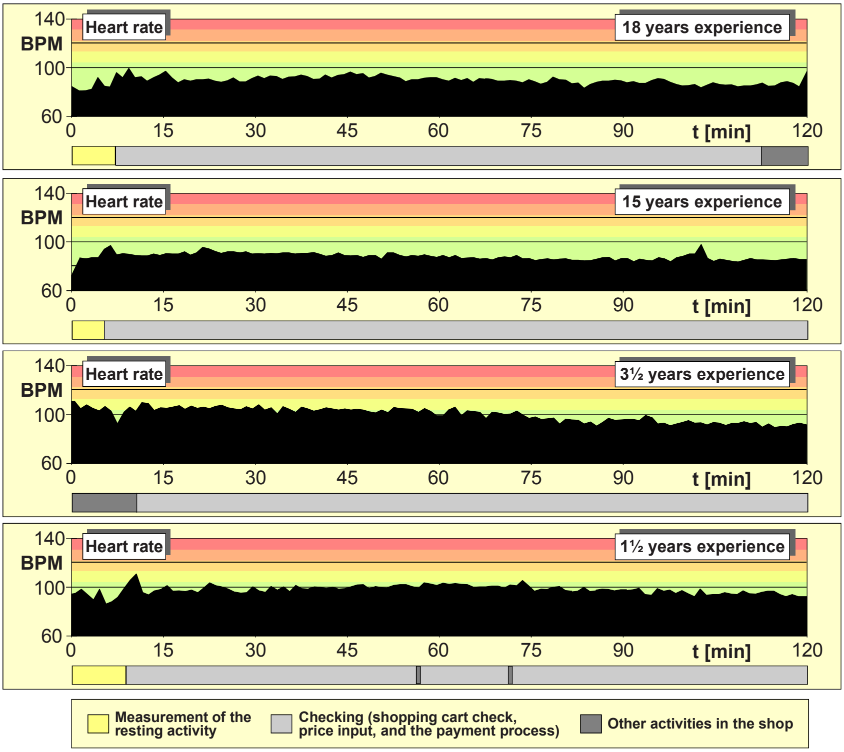

Fig. 28.6: Heart rate (in beats per minute, BPM) of 4 shop-assistants with more or less experience during mainly checking activity (STRASSER & KLUTH 2002)

The heart rate over the 2-hour long measurements remains fairly constant. It rather decreases somewhat over that time period for the analyzed, uninterrupted checkout of all 4 cashiers with more ore less experience (ranging from 1 ½ to 18 years). The measured values of approximately 85 to 100 BPM usually are below the endurance level of the respective employee (i.e. about 35 beats above the resting level when measured during sitting). That means checkout duty is relatively light physical work. But this does not mean that it is unproblematic with any respect. It can be shown that already minor unnatural hand postures (ulnar deviations) are associated with substantial increases in specific muscle strain during the manual entering of prices which can be revealed by the already described electromyographic methods.

Referring to the multi-dimensional approach of recording stress and strain via simultaneous analyses during working shifts it has to be stressed that not everything can be measured with technical devices. However, sometimes decisive impacts of the working conditions can be assessed by work-psychologically oriented structured interviews and subjective rating, as shown in the lower axis of Fig. 28.2. Therefore, social-scientifically-based surveys, i.e. interview data from questionnaires specified to the workplaces to be analyzed are typically also essential for an ergonomic field study. These assessments similar to “paper and pencil tests” have also to be carried out in a detailed manner which gives insight into the causes of complaints as well as their intensity, duration and frequency.

In addition to the simple registering of complaints, i.e., for instance the number or percentage of workers who experience physical problems due to their work in various body parts, such as the left and right side of the hand-arm system or the back, attention must be paid to their intensity, which may range between “very heavy” and “none” (zero) (Fig. 28.7).

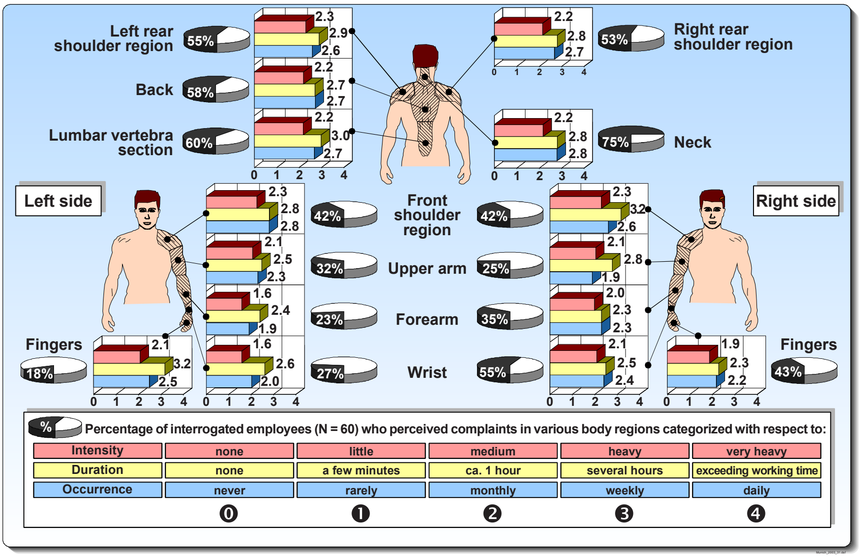

Fig. 28.7: Subjective assessment of complaints. Intensity, duration, and occurrence of complaints in different body regions of afflicted shop-assistants (in %) (IRLE et al. 2002)

Additionally, the duration is of significance, i.e., whether the complaints extend beyond the end of the workday (4) or whether they only persist for a few minutes (1). Furthermore, the occurrence (frequency) of complaints matters, e.g., it makes a difference whether problems occur on a daily basis (represented by the number “4”) or very infrequently or rarely (1).

Ergonomics research approaches must work in the area of conflict arising from the scientific claim of the utilized methods on the one hand and the requested pragmatic simple procedures on the other hand, so that actual workplaces in a company are not misused as a scientific “playground” or field of experimentation. At the same time, ergonomics as an applied science must not be turned into a pseudo science, either.

4 Comprehensive Ergonomics Work Design and Evaluation

The bilateral goal of “optimizing human aspects while maintaining economic efficiency” must be kept in mind in the design of work. Based on the totality of the above-mentioned results of applied work-scientific methods, suggestions for the improvement of working conditions can be derived. Figure 28.8 shows a procedure, which has been used successfully for a number of years, with which the above described goals can be realized.

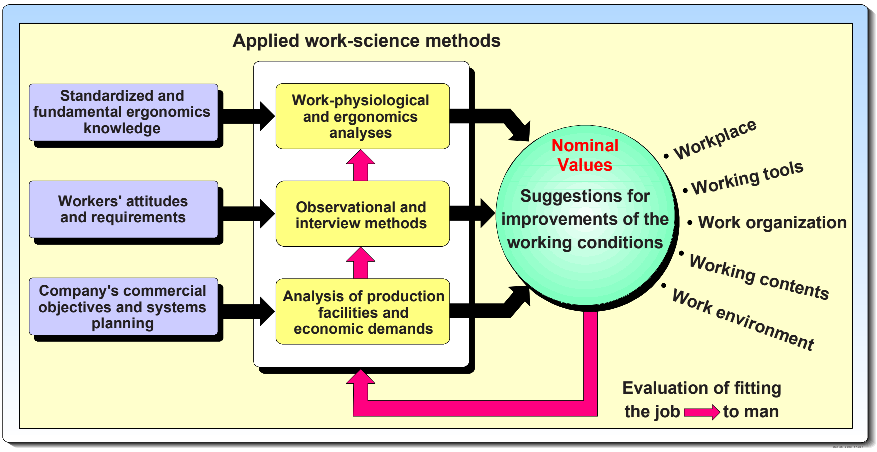

Fig. 28.8: Procedure of applied ergonomics field research (STRASSER 2003b)

Work-scientific field studies must not be limited to analyses of the actual conditions. Instead, nominal values of the working conditions must be developed, with the goal of remedying deviations of the actual conditions from the target (nominal) conditions. Recommendations for improvements must be developed, based on the work-physiological and ergonomics analyses sketched out above which take laws, standards, and rules as well as fundamental ergonomic knowledge into consideration. Real-life work-scientific applications have lately even been considered important enough that they have become legally binding. According to the occupational health and safety act (N N 1997) since already longer than 10 years in Europe, “preventative work safety” must not be secondary to purely economic and technical considerations. A court case may now even be employed to receive “safety and health.”

Coming back to the procedure of applied ergonomics field research, additionally, knowledge must be gained about the workers’ attitudes and requirements, i.e. individual needs of employees via social-scientific surveys, i.e. observational and interview methods. Finally, a company’s commercial objectives and systems planning must be taken into consideration using the available production facilities and obeying economic demands. Thus, suggestions for improvements or alternatives must be developed – ideally in cooperation with the company – for workplaces and working tools, the work organization with work contents, and the work environment.

If the result, as in the example shown in Fig. 28.9, is a new cash register workplace with scanner technology, it should, of course, not be expected, that the solution can be developed ad hoc. Instead, after a first draft several developmental stages of careful acting and working in the spirit of "human factors engineering" is required in order to find an overall optimal solution to sometimes conflicting goals and complex situations.

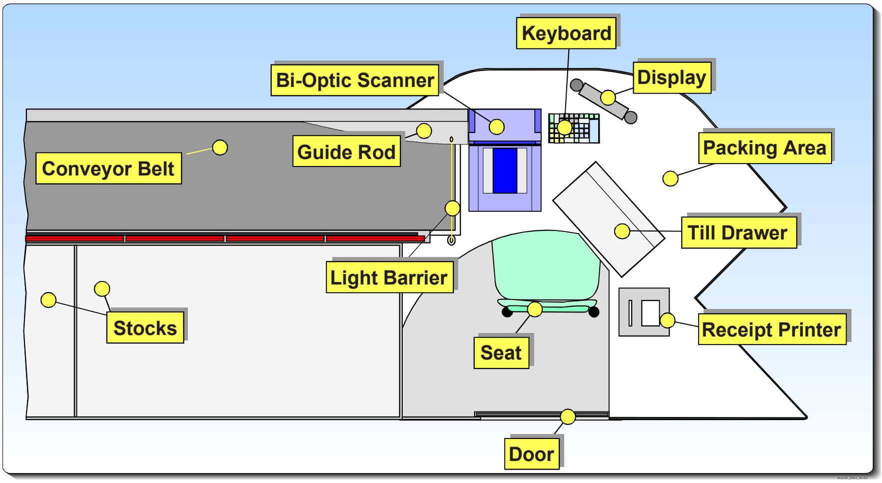

Fig. 28.9: Schematic outline of the first draft of a new scanner checkout (KLUTH 2002)

An example for such a solution is a bi-optic scanner (cp. upper part of Fig. 28.10) which, rather than being directly in front of the cashier, (i.e., in front of a cashier's torso), is mounted in a way which is compatible with the elbow joint, so that items can be moved with a simple sweeping motion of the left forearm from left to right (instead of the traditional more physically demanding right to left). Additionally, the right hand can be used for still occasionally required keyboard input. It goes without saying that according to the lower part of Fig. 28.10, the checkout has to accommodate both 5th and 95th percentile cashiers.

New workplaces should also undergo an evaluation to determine to which extent the taken measures actually are consistent with humane work design. The feedback loop in the process of adjusting all technical and organizational factors to the human body in Fig. 28.8 is meant to indicate that such target working conditions typically must be examined once more to evaluate the fitting of the job to man to ensure, that work has truly been adjusted to human needs.

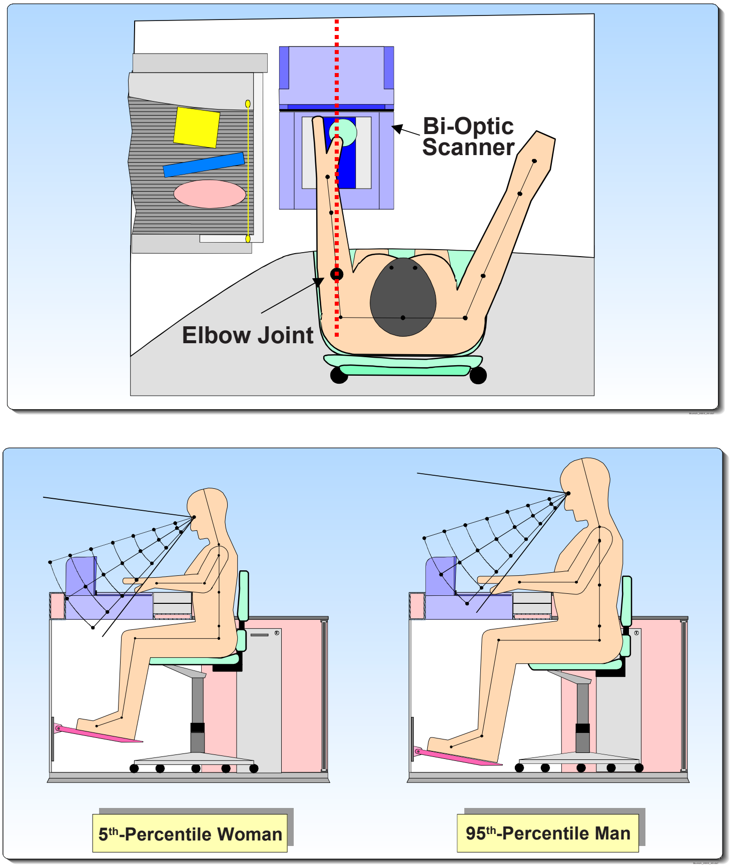

Fig. 28.10: Physiologically favorable positioning of the scanner aligned to the elbow joint (upper part) and checkout accommodating both 5th- and 95th-percentile cashiers (lower part)

These evaluation studies have, of course, been carried out (KLUTH & STRASSER 2003a,b). In order to achieve real-life relevance, it must be ensured that new work structures are accepted by the employees. In this kind of analysis, planning, redesign, or new construction, feedback from individuals who are affected by the measures in the form of direct involvement of the employees in the design of their own working conditions is always desirable which has long been recommended in §§ 90 and 91 of the Works Council Constitution Act of Germany.

Referring again to the "control loop work" (Fig. 28.1), especially the work environment which affects an individual's output as well as the strain on the human body, in extracts, principles, methods, and examples of ergonomic laboratory research will be shown. Compared to field research there are advantages for this kind of research insofar as such investigations which are important for the clarification of basic questions in man-machine interaction or the effects of the physical working environment on man can be carried out with strictly supervisable and exactly controllable conditions.

5 Ergonomic Laboratory Studies Focusing on the Validity of the Energy-Equivalence Principle Applied for Traditional Rating the Physical Environment

In the evaluation of noise, for example, the daily noise exposure level (the former "rating level"), i.e., various sound exposures set in relation to an energy-equivalent 8-h day, can be irritating and misleading as well. For example, the mathematical formula shown in the top part of Fig. 28.11 promising an exact calculation of the rating level L_{Ard} from several measured levels L_i during specific exposure times t_i within an 8 h workday leads to the same value for both of the noise exposure situations shown in the lower part of Fig. 28.11.

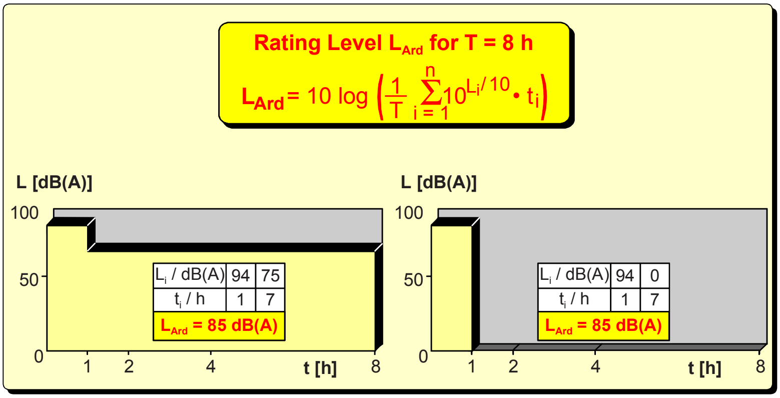

Fig. 28.11: Elucidation of discrepancies in rating noise via the 3-dB-exchange rate (STRASSER & IRLE 2005)

Both 94 dB for 1 h as shown in the right part as well as 94 dB and the additional 75 dB for the remaining 7 h in the left part result in a L_{Ard}-value of 85 dB(A). Physically seen, this is correct, but it is comparable to "filling up" of quiet periods with noise and from a psychological point of view it is likely that nobody would prefer a situation as described in the left part. Provided that the noise distribution shown in the left part of Fig. 28.11 would stem from 2 machines, strange effects would also result with respect to technical approaches of noise control. If an engineer in this case would decide to completely insulate the machine which emits the lower level, the daily noise exposure level would not be influenced at all. The application of the measure "daily noise exposure level" consequently allows these strange ratings, as long as the lower value of noise remains a certain amount below the peak levels. For an equal exposure time, a difference of only 10 dB between the two levels is already enough to neglect the lower level, which absolutely agrees with legal regulations, standards, and national or international guidelines. It is also possible, as shown in Fig. 28.12, according to the halving parameter q = 3 to equate, e.g., 85 dB/8 h with 88 dB/4 h, 91 dB/2 h, 94 dB/1 h, 97 dB/30 min, 100 dB/15 min, and finally 113 dB/45 s or even with 140 dB/100 ms. One could say, that an acoustic "slap in the face" could be turned into the equivalent number of caresses per day. The traditional work safety regulations also permit the energy-equivalent splitting up of, e.g., 113 dB/45 s into 9,000 impulses with a duration of 5 ms each, since 9,000 × 5 ms is equal to 45 s. However, laboratory experiments leave no doubt that the human hearing does not respond to these different exposures in the same fashion.

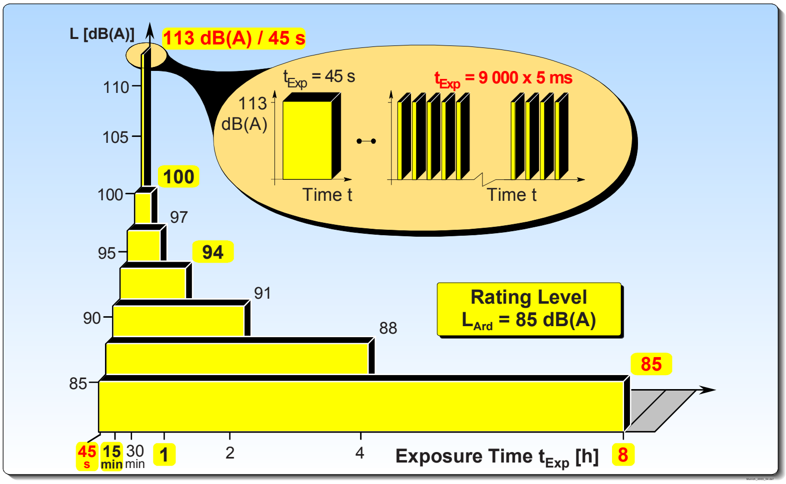

Fig. 28.12: Sound pressure levels of different durations leading to an equal rating level when applying the "3-dB-exchange rate" (STRASSER & IRLE 2006)

For example, hearing threshold shifts of 20 dB and more above an individual hearing threshold can be identified audiometrically (especially with 4 kHz) as a result of a preceding exposure to noise levels which are permissible in the production sector.

Even though the maximum Temporary Threshold Shift (TTS_2) is important, the main focus must be on the restitution which can vary greatly from just a few minutes to several hours. The average hearing threshold shifts of 10 Subjects – after an exposure to 94 dB for 1 h – amounted to approximately 25 dB, which took approximately 180 min, i.e., 3 h to subside. If the noise exposure of 94 dB/1 h was compressed into equivalent 113 dB/45 s, the threshold shifts as well as the restitution times were drastically reduced. If the noise exposures were split up into energy-equivalent impulses, however, e.g., into 180 impulses of 250 ms, each, the threshold shifts as well as the restitution times once again increased (Fig. 28.13).

The restitution time after 450 impulses of 100 ms each were approximately 360 min, i.e. 4 h, and after a further increase in the TTS and the restitution time at 1,800 impulses, at 9,000 impulses of 5 ms, each, restitution times reached up to approximately 600 min, i.e., approximately 10 h were necessary. In summary, as visualized in Fig. 28.13, an Integrated Temporary Threshold Shift, i.e. a threshold shift sum IRTTS of 147 dBmin after the short, yet intense, noise exposure in TS II and of more than 2,400 dBmin after the 9,000 5-ms impulses in TS VI led to a ratio of 16 to 1 for the physiological costs, costs which the hearing must pay for the energy-equivalent noise exposure.

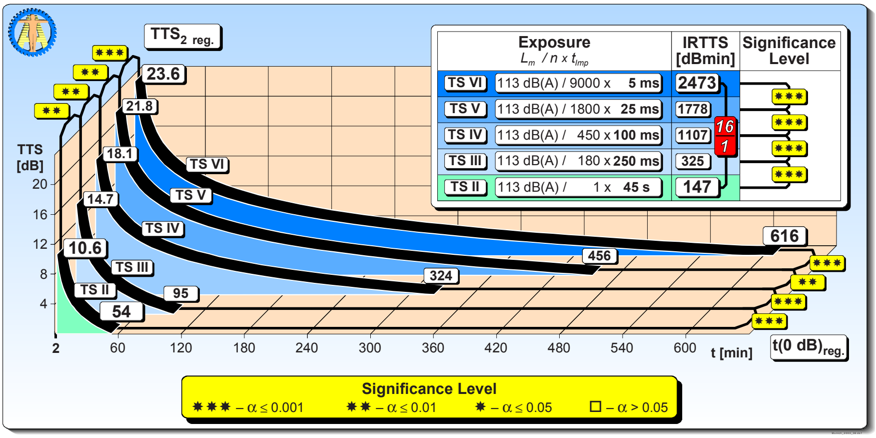

Fig. 28.13: Restitution time course TTS(t) with characteristics TTS$_{2\ reg.}$, t(0 dB)$_{reg.}$, and physiological cost IRTTS as well as symbolic labeling of significance levels for the differences between the responses to the exposures with equal exposure level L_m = 113 dB(A) and exposure time t_{Exp} (n x t_{temp}) (according to the one-tailed WILCOXON-Test) (IRLE et al. 2006)

These results have to be seen as a contradiction to supporters of the dose maxime who like to cite Paracelsus, who is credited with the phrase “dosis facit venenum”. By now means does that imply, however, that alternating high and low immissions should be expressed as a single mean value to describe a workplace’s typical amount of stress. A thorough study of Paracelsus’ work reveals that his phrase – reported 450 years ago – reflects a medical doctor’s experience and knowledge of toxicology that medication (the extract of a medical plant) in several smaller amounts (the “right dosage”) has healing effects while the same amount administered at once (the dose) could be fatal. Impulse noise with levels above 120 dB but also with levels of only 113 dB as used here which until 2007 were legally permissible on the base of an energy-equivalent rating (daily noise exposure) level of 85 dB(A), is comparable to a hurricane or tornado inside the ear which cannot be expected to pass over the carpet of hair cells without consequences. This is similar to a gust of wind which sweeps over a field of grain or blows up a sail which is quite different from a continuous, long-term breeze. For ethical reasons, however, laboratory studies, with dangerously high levels must not be used in tests involving human test subjects, even through much more drastic effects on man could be shown.

Finally, the results of an additional test series on the effects of noise and exposures to different kinds of music shall be reported. After white noise, i.e., meaningless sounds, at a mean level of 94 dB for 1 h, threshold shifts around 20 dB occurred which were slow to subside among the group of 10 Subjects (Fig. 28.14).

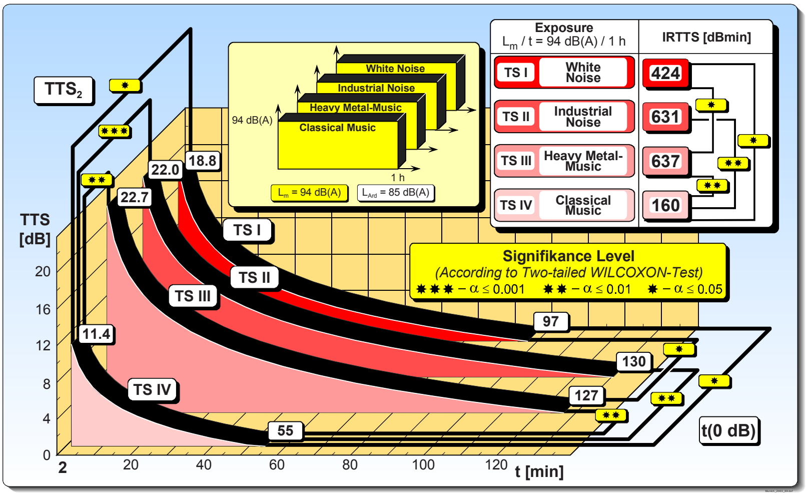

Fig. 28.14: Restitution time course TTS(t) with values of $TTS_{2\ reg.}$, $t(0\ dB)_{reg.}$, and IRTTS of the 4 energy-equivalent exposures (STRASSER et al. 1999)

Equally loud and equally long lasting industrial noise led to barely higher threshold shifts, but substantially prolonged restitution times. This type of noise is encountered in the machinery of a metal-processing plant. Heavy-metal music with songs by Gun's and Roses and AC/DC, i.e. famous international bands, led to almost identical threshold shifts of about 20 dB, even though the test subjects were quite taken with this kind of music. Classical music, however, was associated with threshold shifts which were reduced by half and which completely subsided within 1 h.

Thus, the 4 energy-equivalent sound exposures with a daily noise exposure level of 85 dB(A) were associated with significantly different physiological responses.

If all the measured threshold shifts of this test series are put in relation to those of industrial noise as shown in Fig. 28.15, heavy-metal seems to be closely related to industrial noise, and it becomes apparent that with only 25% of the threshold shift, the human hearing is rather made for classical music.

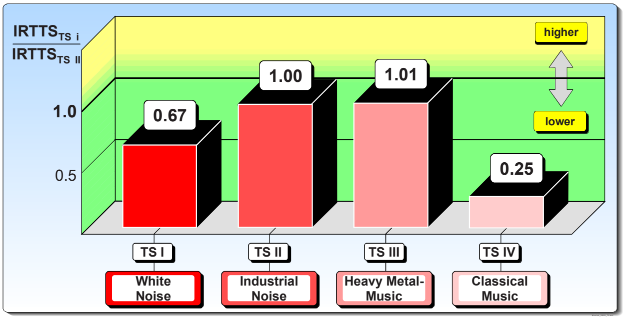

Fig. 28.15: "Relative physiological cost" of the energy-equivalent exposures ($IRTTS_{TS\ i}/IRTTS_{TS\ II}$)

6 Conclusion

In each work system an optimal output can only be achieved if the technically and organisationally devisable system elements are coordinated with the capabilities and performance limits of the human being. As in purely technical systems, compatibility between the respective system elements and the physiological characteristics including psychological and social needs of the workers and the exposed subjects, respectively, is necessary. This is also true for the minimization of repercussions for a human being, i.e. strain, as well as undesirable effects such as premature fatigue and loss of motivation, work-related illnesses or even occupational diseases.

The correct ergonomic design of work systems, as an important prerequisite for occupational work safety, requires that the "players" in a company possess the relevant fundamental qualifications, as well as – and this is very important – the ability and authority both to make decisions and to implement them. Any ergonomist or design engineer, any safety expert or doctor in occupational medicine, any human resources director or employee representative who is responsible for occupational safety issues must have a comprehensive, well-founded, and consistent knowledge of the relevant areas. Their actions must not be limited to a knowledge of minutiae, or of simple and formalized actions based on laws, accident prevention guidelines, safety rules, norms and standards, national or international guidelines produced by professional institutions, checklists, or the introduction of work safety management systems without any substantial content.

The planning and design of workplaces, be it in an administrative office or in the production sector, requires more than purely remembering and applying predetermined "recipes". Instead, the overall context must constantly be considered and interdependencies between the various goals must always be kept in mind, in order ultimately to achieve consistently comprehensive, rather than merely sectoral, efforts for the design of working conditions which are ergonomically satisfying.

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29 Modular Concepts for Integrating Ergonomics into Production Processes

Ralph Bruder, Holger Rademacher, Karlheinz Schaub, Christophe Geiss

1 Modular Concepts for Ergonomics

It is a major concern of ergonomics to align humanity with economic efficiency. Ergonomic approaches that are introduced after the requests from employees or even worse after the first diagnoses of work-related health problems follow a corrective manner, and therefore cannot fulfill this concern. Especially the integration of corrective measures into completed work design is in most cases difficult and high priced. Absence due to illness of staff members is connected to premium rates, breaking-in costs of new staff members, capital expenditure, insurance contributions of possible unused capital equipment, or increased costs for planning and controlling on the side of management. In addition, there are costs of potential production downtimes and quality defects (LANDAU 2002). But even the reintegration into occupational environment of a sick staff member is related to costs when the employee has to be introduced to a new or redesigned workplace. Although, there are many companies (especially small and medium-sized enterprises, SME) that lack of methods and concepts for the integration of effective structures for a preventive-oriented health and safety management. Hence, occupational and outside occupational stakeholders have to have methods and management instruments that support re-orientation at new task areas.

To fulfill the demand for conceptual instead of corrective ergonomics it is necessary to align ergonomic methods and findings for analysis and design of work systems with the established processes in companies for product development and production planning.

In the following a conceptual approach consisting of five modules will be described (Fig. 29.1) that is aiming at establishing a continuous and holistic consideration of ergonomics in different phases of product planning processes (BRUDER et al. 2008). By using all five modules a company might be able to fulfill the often formulated commitment of bringing together the demand for increasing productivity

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with the necessity of conserving (or even increasing) the work ability of their workers.

A basic step is the general introduction of structured assessment methods and tools that describe adequately physical and mental workload in the particular company. In most cases companies already have standard methods, but these are insufficient or not adequately prepared for the particular application.

A first step would be to extend or adjust these methods or if necessary introduce other assessment methods that are more adequate for the particular situation of risk assessment or for evaluating the quality of ergonomic design (SCHAUB et al. 2008).

The second module takes into account that a simple introduction of tools will not be enough for the most possible utilization of ergonomic processes. Tools and connected processes should be designed in a way that they can be introduced in different phases of the product development process as well as contiguous areas of application for new users. A further development of the current tools or the introduction of new advanced tools is precondition here as well.

Furthermore the usage of the results of the stress analysis is part of the second module. In this context the classical ergonomic design of worksystems and workplaces has to be mentioned. But also the design of work organizations (e.g. job rotation) and the introduction of new modes of operations might be a suitable way to reduce the risk of health problems indicated by high values of stress.

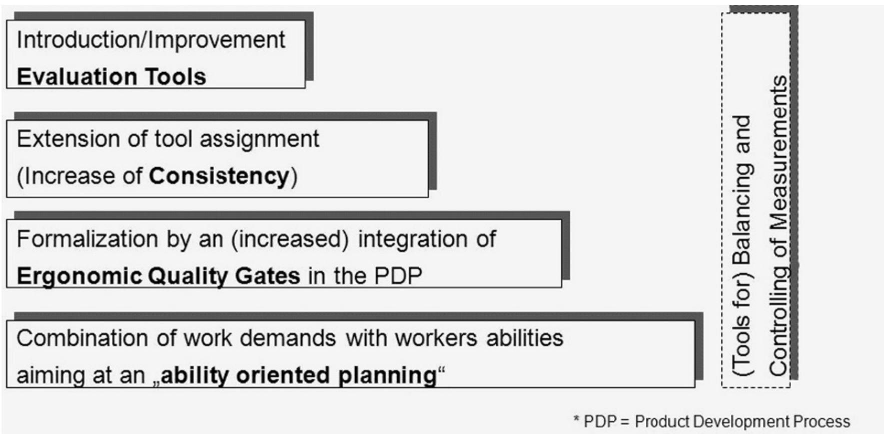

Fig. 29.1: Five modules for integrating ergonomics into production planning processes

A next logic step for a more standardized evaluation of quality of ergonomic design or risk assessment along the production planning process is the integration of Ergonomic Quality Gates in order to formalize that process or more precisely to regularize production systems that describe that process. This includes the description of points in time, contents, assessment criteria, consequences, and for example informing routines between participating persons concerning further use of results.

As it can be seen in Fig. 29.2 the data collected in the different steps of the product development process are not only used for the actual process (model 1.0) but the data are also helpful for the planning of future processes (model 1.x). So if the outcome of an ergonomic evaluation is that you should make some changes and maybe it is not possible to implement those changes (because of economic and/or constructive restrictions) at the existing production line the results of the ergonomic evaluation will be helpful for the setting of the next production line.

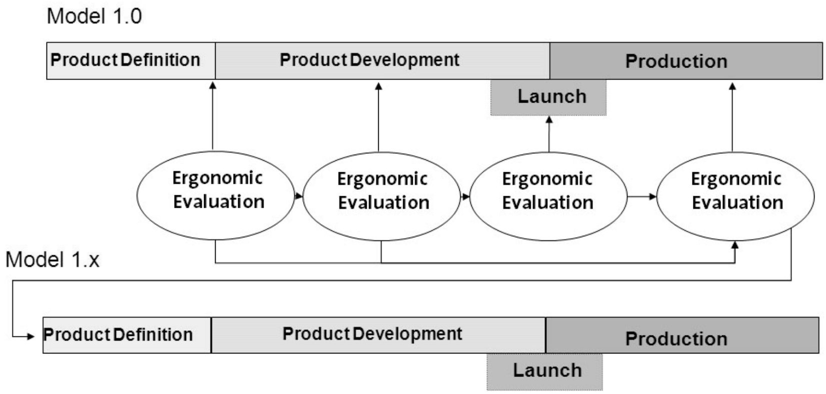

Fig. 29.2: Consideration of ergonomic quality gates within the Product Development Process

The fourth part of the conceptual ergonomics module concept is concerned with the fitting of employees to workplaces. In the first three modules only work place requirements are regarded. A further step is to connect the capability of employees to those requirements. Those capabilities might be related to one special worker which is useful in the process of the reintegration of handicapped workers (e.g. after having an accident). But it is also possible to have profiles of capabilities of whole groups of workers where the average capability of representatives of the selected group for special performances (e.g. body movement, exertion of forces) is described. Furthermore the profiles for the actual population of workers can be used as well as the profile of the expected population in e.g. ten years ahead. Comparing the work recommendations of a newly designed production system with the capabilities of a future population is an important aspect of reacting to the challenges of demographic change (RADEMACHER et al. 2008).

The decision to use or not to use primary prevention measures depends on respective basic conditions, such as company principles, guidelines for health promotion, etc., in addition to standards of evaluation. A fixed connection of primary prevention – also from outside of production and production planning – is only possible when companies record benefits. But these benefits are difficult to categorize. As a result management tools for accounting and controlling are necessary to make benefits transferable to decision-makers.

2 Application of Modular Concepts in Practice

In the following a case study performed as a cooperation between the Institute of Ergonomics of Darmstadt University of Technology (IAD) and a car manufacturer will be described. The aim of this study is to optimize the working conditions in production areas of the car manufacturer. At the beginning of the project there was no process of ergonomics implemented in the production system.

Only a self-developed assessment tool for physical and mental workload existed. But this tool was not well accepted by workers' representatives because of its obviously limited validity and objectivity in many cases. Even the employer had doubts whether this tool was appropriate to evaluate the current working conditions. In addition, the company had only one expert in ergonomics, who left in the run-up to the project.

Another important reason for the launch of this project was the rising number of absence from work due to musculoskeletal disorders and diseases as well as the increase in average age of the workforce. Therefore the goals of the project were defined and addressed in five stages corresponding to the first two modules described in the previous chapter:

(1) Development and application of a valid and objective risk analysis method for the identification of unacceptable physical stresses in different production areas (Module 1)
(2) Definition of improvements (design of technical work conditions or introduction of new modes of operation) to prevent unfavourable working situations (Module 2)
(3) Implementation of standardized work instructions to help workers doing their job in an ergonomically favorable way (Module 2)
(4) Analysis and optimization of existing models for job rotation (Module 2)
(5) Realization of a comprehensive approach to embed a process of ergonomics in the production system and in the mindset of all relevant and responsible persons (Module 2)

2.1 Results of Stress Analysis as basis for Design Requirements

The tool for ergonomic analysis grants load points for ergonomically unfavorable working conditions. A traffic light three zone rating system is associated depending on the overall score obtained as result of an analysis with the method. It is based on the European Assembly Worksheet (EAWS) which is discussed in detail in SCHAUB et al. (2008).

The tool consists of four sections for the evaluation of working postures and movements with low additional physical efforts (< 30–40 N or 3–4 kg respectively), action forces of the whole body or finger-hand system, manual materials handling and repetitive loads of the upper limbs.

Sections one to three base their evaluation on physiological and biomechanical criteria; section four is based on medical and epidemiological data. With respect to the different evaluation approaches the results of sections one to three are combined to a “whole body” exposure, whereas section four indicates the load situation of the “upper limbs”. The overall result is the worst case of “whole body” score and “upper limbs” score (Fig. 29.3).

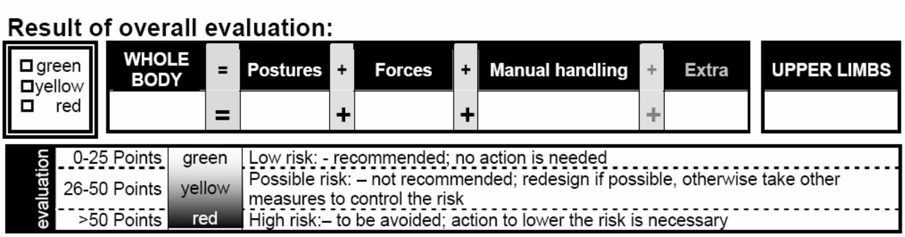

Fig. 29.3: Overall evaluation scheme (overall estimation considers “whole body” and “upper limbs”)

In total, 45 work stations were analyzed and mostly awkward body postures and upper limb loads in repetitive tasks were identified to be responsible for unfavorable working conditions in the sample of work stations (Fig. 29.4).

If single types of workload are regarded only, the situation is not very alarming in this sample. Only the amount of awkward body postures can be considered as “improvable”. But this focusing on single types of workload disregards that often complex workload constellations are present at a work station (especially on vehicle assembly lines).

The fourth column “postures + action forces + manual handling” represents the integration of the single evaluations (overall results of the 45 work stations). It visualizes that the workers are exposed at many more work stations to a “possible” or “high” risk for musculoskeletal impairments.

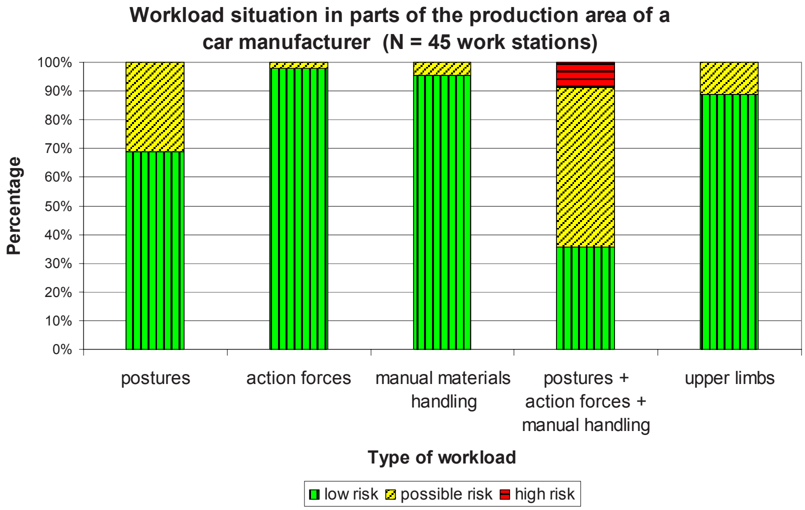

Fig. 29.4: Results of stress analysis and derived risk categories at the evaluated work stations

2.2 Improvement of Workplaces Based on Risk Assessment

After the analysis of the work stations all of them with conditions inducing a possible or a high risk for musculoskeletal impairments were examined with regard to possible improvements of the workload situation. Ergonomic improvement measures may be categorized as follows:

a) ergonomic mode of operation
b) (simple) changes in the production process
c) (re)design of production elements
d) providing an assembly aid
e) anthropometric workplace design.

Figure 29.5 shows an example for a reduction of upper limb loads only by using both hands in order to wipe off sealing material from the car body. This simple change in working habit (possible with respective training) leads to a significant decrease in load frequency for the dominant limb. Some operations at this work station can be performed with better arm and hand postures when using the suitable upper limb (left or right side) due to improvement of accessibility.

Fig. 29.5: Removal of dispensable sealing material

Another example for a changing in the mode of operation is shown in Fig. 29.6. The worker has to twist the wiring harness and insert the clip into a hole of the car body. The wiring harness is pretty stiff and hard to move, so relatively high forces are necessary which lead to a possible risk for the finger-hand system. In addition, a strong abduction in the wrist occurs, augmenting the risk level. As a result of the observations most of the workers performed this operation only with one hand. If a worker uses both upper limbs, the force level will be reduced, the gripping conditions will be improved and the abduction in the wrist will be avoided. In order to lower the degree of torsion the clip should be inserted before the connector at the end of the harness will be inserted (change in operation sequence).

The just described work station is also an example for a possible change in the production process as well as a redesign of an element. It may be an option to insert only the clip without the harness at a previous work station and to combine the clip with a cable tie. Then the harness can be fixed easier to the car body by using the cable tie. Or the harness supplier (different company) may fix the clip to the harness with a different orientation, so that the worker doesn't have to twist it so much.

In Fig. 29.7, a work station is shown, where the anthropometric design does not match to the work operations. The worker has to carry out most of the tasks in the upper region of the vehicle with arms over shoulder or head level. By simply increasing the height of the platform (brown floor area), the worker will be able to do most operations at chest or waist level which lowers the risk for musculoskeletal impairments significantly.

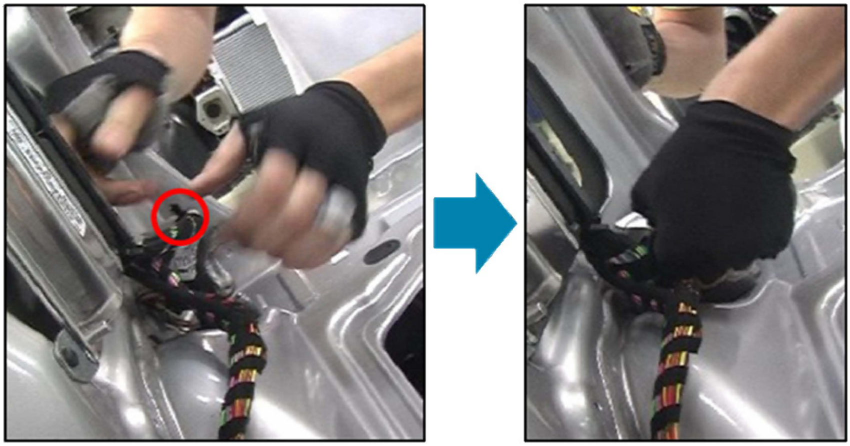

Fig. 29.6: Installation and connection of the electronic control unit

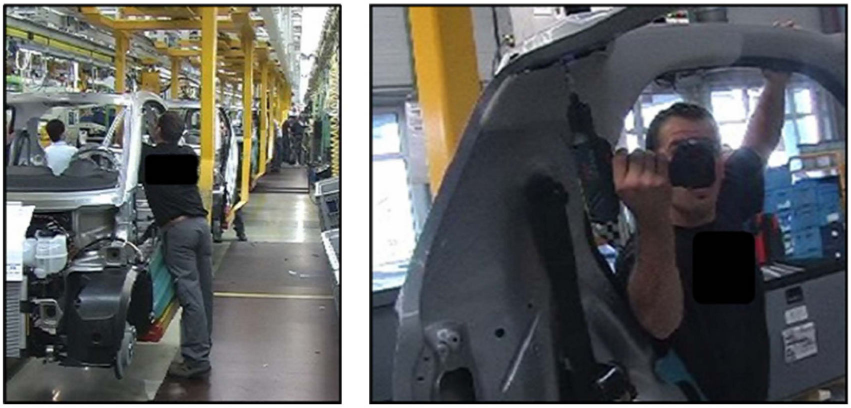

Fig. 29.7: Assembly of several interior trim panels

2.3 Recommendations for Job Rotation Based on Stress Variations

A literature research showed that the primary recommendation for the design of a rotation schedule between work stations is to realize alternations of the demanded muscle groups (MATHIASSEN 2006. PUTZ-ANDERSON 1988, WANDS & YASSI 1993). This principle can be named as “targeted stress variations”. The more similar the tasks at the work stations, the lower the effects of job rotation (ELLIS 1999).

Based on the principle of stress variations a procedure for the definition of job rotation models was developed in the project. It consists of the following five steps:

a) definition of the stations which shall or can be included in the rotation model

b) compilation of a similarity matrix for all stations determined in step 1
c) definition of the rotation interval
d) allocation of work stations to the workers
e) calculation of mean value of "recovery" for each worker depending on the work stations integrated in his rotation cycle

The main element is a similarity matrix where each entry is the result of a pair-wise comparison between work stations that are part of the rotation model. Two work stations are compared with regard to the similarity of the physical stresses affecting the worker. The result of the comparison is an estimation of the potential degree of recovery from physical workload induced through the changing in stress conditions. The potential degree of recovery is expressed by a value between zero and three points (ordinal rank-order scale with an increment of 0.5 points).

The comparisons of the stress conditions of different work stations must be done by ergonomic experts (expert rating). The rating should be based on the results of workload analysis. Table 29.1 shows the scale used for the similarity matrix. This approach (esp. the scale) is based on a study done by SCHREIBERS et al. (2006).

Table 29.1: Definition of the recovery scale

score	similarity of both work stations	Opportunity for physical recovery
0	highly similar, the same body parts are affected	No
0.5	very similar	Minimal
1	similar with some slight differences	Low
1.5	less similar with moderate differences	Fair
2	Different	Good
2.5	very different	Very good
3	totally different	Excellent

It is important to mention, that the similarity matrix can be symmetric but it does not have to be and often it is asymmetric, because for example the change from work station A to work station B does not have the same recovery potential as the change from work station B to work station A.

Concerning the definition of a rotation interval, no definite rules were found in literature. Some authors recommend an interval length between one and two hours for rotations within a work shift (ELLIS 1999, THARMMAPHORNPHILAS & NORMAN 2004).

But an adequate length always has to be determined with respect to the (organ-izational) conditions in the relevant production system. Otherwise negative effects on for example productivity and quality might interfere with the intended positive influence of a rotation schedule.

The number of work stations that should be considered within a rotation cycle depends on the interval length and the working conditions in the relevant area. In the case study presented in this paper all rotation models were defined on team level (between 7 and 15 work stations), but not all stations of one team were attributed to the rotation loop. With respect to productivity and quality issues as well as the scores in the relevant similarity matrix, it was recommended to use between three and five work stations. In some cases it might be effective to even consider only two stations for a rotation within the work shift.

Different schedules for job rotation can be compared by calculating the mean of all relevant recovery values from the similarity matrix to find the best rotation cycle under given conditions. The cycle with the highest mean value for recovery rate is the one that should be chosen. A mean value of 1.5 may be defined as target value in order to get a rotation model with significant recovery effects. Though, the calculation of mean values is theoretically not allowed for ordinal scales, in this case it might be an acceptable way of simplification. If the median is used, the overall result may be biased, especially when the rotation cycle contains less than four work stations (low sensitivity of the median).

2.4 Introduction of a Sustainable Training Concept

In the last stage of the project about optimization of the working conditions in a plant of a car manufacturer all parties agreed, that it is important to get the relevance of ergonomics across all relevant decision-makers in the company. The awareness and acceptance for a holistic consideration of ergonomics should be increased. Therefore a training program was developed consisting of four modules with specific intentions and target groups.

The first module schedules the transfer of basics in ergonomics in order to embed this basic knowledge into the continuous improvement process (CIP) already implemented in the production system. This should promote the ergonomic design of work stations and an ergonomic way of working of the workers at the production lines (inter alia using work instructions).

All industrial trainers, foremen, team spokesmen as well as experts in ergonomics of the company (experts are trained in the application of the method for stress analysis) and representatives of a health and safety committee of the works council were selected as participants in the first training module.

In a second module, methods of ergonomics and educational science will be trained to enable the training participants to systematically document and communicate recommendations related to ergonomics within the company. The target groups for this module are companies' industrial trainers and experts in ergonomics.

Only the experts in ergonomics are intended as participants in the third module of the training program. The content of this training module is the methodology to derive improvement measures in ergonomics based on the results of workload analysis with the tool for ergonomic analysis. This requires a previously completed training which cannot be granted to all the other decision-makers due to cost reasons.

An ergonomics oriented design of the work organization (esp. job rotation) is the topic of the fourth training module. The procedure described earlier in this paper is explained to the experts in ergonomics as well as foremen and team spokesmen, because they are defining the daily rotation schedules in this production site.

3 Conclusion and Outlook

Ergonomics that is introduced into an early stage of production processes, right from the beginning of product design and development processes is an indispensable step to introduce humanity and economic factors into successful production. Corrective ergonomics as it is common nowadays always intervenes too late. This intervention is in general combined with additional costs. Conceptual ergonomics as it is described in the general five module approach and as it is transferred into practice described in the case study starts before those costs can rise.

In a further project of the Institute of Ergonomics of Darmstadt University of Technology the conceptual approach is practically tested. KoBRA* (Cooperation Program for Normative Management of Workload and Risks at Physical Work. The KoBRA project is funded by Federal Ministry of Labor and Social Affairs (BMAS) within the scope of the program of reducing work-related diseases. In 2007 the program emphasizes on "workload of musculoskeletal-systems while working – integrative prevention approaches realized in practical use".) surveys processes on five companies and transmits its findings into a network for a broad audience.

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30 Methods for Measuring Mental Stress and Strain

Martin Schütte

1 Introduction

It is generally agreed that the measurement of work stress and strain provides indication of the appropriateness of work design, i.e. information which is necessary for verifying whether working conditions are in accordance with the criteria of human-centred design (LUCZAK 1998). Accordingly, such an analysis represents an important pre-condition for the evaluation of work-systems. Furthermore an assessment of mental workload is required by legislation, such as the "Machinery Directive" or the "EU Directive on the minimum health and safety requirements for work with display screen equipment". Both directives contain the obligation to measure mental stress of operators or employees.

However, a universally accepted concept of mental workload is missing and rather different conceptions concerning human information processing exist. The single resource theory assumes that the processing of information presupposes the supply of an adequate quantity of energy. Various internal processes which may take place in sequence or in parallel receive energy from a single undifferentiated pool, whereas an allocation policy mechanism governs the supply of resources (KAHNEMANN 1973). Other approaches, as e.g. the discrete stage model, assume that the information processing system is composed of various elements possessing a discrete function in the information transfer of the system. A processing stage can only be passed through if the preceding stage is completed (STERNBERG 1969). Accordingly, human information processing is therefore assumed to be strictly serial. In contrast, the multiple resource theory is based on the assumption that the capacity or energy necessary for various internal activities during information processing is divided into specific reservoirs (WICKENS 1984). The cognitive energetical stage model (SANDERS 1983) integrates the structural and energetical approaches of human information processing. The model considers three energetical supply mechanisms with the two more basic mechanisms arousal and activation are linked to input and output stages of information processing. The

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basal mechanisms are coordinated und supervised by a third mechanism, the effort system. An evaluation mechanism mediates the information about the basal mechanisms. Although the concept of situational awareness (ENDSLEY 1995) does not aim at the identification of different information processing mechanisms, it accentuates the control of attention during control of complex technical systems. This concept does not aim at the identification of several information processing mechanisms. Situational awareness encompasses the perception, comprehension and anticipation of events. Working memory and attention pertain to those factors most limiting situational awareness. Therefore, situational awareness represents an agent, facilitating the coordination and processing of information coming from different sources.

2 Classification of Measurement Procedures

A multidimensional concept of mental workload is consistently postulated because the complexity of working conditions goes along with demands on different human information processing mechanisms. For an analysis of mental workload different investigation levels such as task demands, individual modality of task completion and the resulting human related consequences must be taken into consideration. Several measurement procedures are available measuring different aspects of mental workload. Only some procedures explicitly refer to specific theoretical models of human information processing.

In order to facilitate the selection of an suitable measurement procedure a classification system is suggested considering the terminology as proposed in DIN EN ISO 10075-1. According to this standard, all assessable external influences affecting an employee mentally are called mental stress. The immediate consequences of mental stress within a person depending on the individual habitual and actual preconditions as well as the particular coping styles are called strain. Correspondingly, the measurement procedures were classified into approaches for measurement of stress and strain.

3 Measurement of Mental Stress

Regarding the measurement instruments aiming at the determination of stress, two main groups can be distinguished. Approaches developed in engineering often refer to the technical performance of work or the work functions. Psychological approaches rather concentrate on the occurring interactions between the employee and his/her work.

3.1 Approaches Developed in the Field of Engineering

Methods attributable to engineering disciplines (Table 30.1) for documentation of mental stress often use quantitative parameter compatible to those for describing technical systems (SHERIDAN & FERELL 1974).

Table 30.1: Methods for measuring mental stress (SCT: Supervisory and control tasks, ST: Supervisory tasks, ATC: Air traffic control tasks, HCI: Human computer interaction, PT: Piloting tasks

Name of the approach	Literature	Tasks	Stress related parameter
Information theory	Senders 1964	SCT	Relative proportion of monitoring tasks
Control Theory	Rouse 1980	SCT	Linearity and time related stationarity of the human transfer behavior
Queuing Theory	Rouse 1980	ST	Relation between required and available time
Fuzzy Theory	Zadeh 1965	SCT	Quality of the used rules
Algorithm Theory	Matern 1983	SCT	Number of operations and decisions
Markov-Chains	Haccou & Meelis 1992	ACT, HCI	Information content of operation sequences
Production Systems	Anderson 1983	PT	Number of productions Number of arguments of the if component
TTA	Stone et al. 1987	PT	Relation between required and available time
TLAP	Parks & Boucek 1989	PT	Complexity of displayed information
SWAM	Linton et al. 1977	PT	Time related load of the human information channels
Workload Index	North & Riley 1989	PT	Requirements concerning attention Number of simultaneously feasible tasks
TASCO	Ellison & Roberts 1985	PT	Task difficulty Number of failures during task completion
SWAS	Holley 1989	PT	Number of simultaneously feasible tasks
HOS	Harris et al. 1987	PT	Frequency of task occurrence Task execution time
SIMWAM	Kirkpatrick et al. 1984	PT	Relation between required and available time Number of accomplished tasks

The advantage is that items for measurement directly refer to the same aspects of technical components that should be considered for design improvements. The vast majority of methods can be applied in settings, where the human operator performs monitoring and control operations.

Due to an increase in automation, for example in aviation and transportation those methods designed for the analysis of monitoring and control tasks will become more important.

Some of the instruments such as TTA, TLAP, SWAM, W/Index and TASCO can be used for predicting the level of stress for a planned workplace. It is assumed that adequate/optimal positioning of displays and control elements can ensure optimal task performance in given time. Accordingly, these approaches provide information about the feasibility of tasks and time constraints during task accomplishment. The above mentioned instruments assume that task execution happens successively and the human information processing system is a central processor with limited channel capacity. The only exception is the W/Index which is based on the multiple resource theory. An application of the simulation tools like SWAS, HOS and SIMWAM require a detailed task analysis. They additionally intend to reproduce essential characteristics of the human operator by considering variations in task execution times or parameters related to human perception, cognition and motor function. The simulation approaches mainly provide information about time related aspects of task feasibility. SWAS is based on the multiple resource theory whereas the other simulation procedures assume that tasks are to be completed sequentially.

3.2 Psychological Methods

The psychological methods for measuring demands of mental tasks are analyzed with respect to the commonly used criteria reliability and validity (Table 30.2). However, the instruments should also be evaluated with regard to their sensitivity and diagnosticity. A measurement procedure differentiating between for example low, moderate and high stress levels meets the criterion of sensitivity. An instrument responsive to different kinds of stress satisfies the criterion of diagniosticity. Both aspects point to the application area of an instrument and facilitate the selection of an instrument adequate for an intended measurement for instance in a factory. The psychological measurement procedures depicted in Table 30.2 are not only suitable for monitoring and control or supervisory tasks but also for office work and manufacturing.

The SWAT, NASA-TLX as well as the Cooper-Harper-Scale, Bedford-Scale and ZEIS-Scale are suited for determining the temporal course of stress levels since these instruments can be applied without much effort. Therefore these scales can be used for repeated measurements. SWORD and Workload Profile only allow a retrospective measurement of stress due to the high costs for the application of the procedures. The remaining approaches such as the DTV-AET, TAI, TBS-GA, VERA-G, ATAA, FEMA and VAB are especially useful for the analysis of the current state of a workplace and for checking the effects of accomplished (re-)design measures.

Table 30.2: Psychological methods for measuring mental stress (*black circle*: criterion was analyzed, *white circle*: criterion was not analyzed)

Name of the approach	Literature	Application Area	Reliability	Validity
DTV-AET	Haider & Rohmert 1981	Office work	●	●
TAI	Frieling et al. 1993	Universal	●	○
TBS-GA	Rudolph et al. 1987	Mental tasks with and without computer support	●	●
VERA-G	Resch 1994	Mental tasks	○	○
ATAA	Wächter et al. 1989	Tasks in production	●	●
FEMA	Tielsch et al. 1993	Industrial workplaces equipped with new technologies	●	●
VAB	Debusmann et al. 1991	Office work	○	●
Stress Questionnaire	Pfendler & Schubert 1985	Supervisory and control tasks	○	●
SWAT	Reid & Nygren 1988	Determination of Mental Load	●	●
NASA-TLX	Hart & Staveland 1988	Determination of mental Load	●	●
Workload Profile	Tsang & Velazquez 1996	Determination of mental load	●	●
Cooper-Harper Scale	Cooper & Harper 1969	Piloting tasks	●	●
Bedford Scale	Roscoe 1987	Piloting tasks	○	●
ZEIS	Käppler 1993	Vehicle guidance	●	●
SWORD	Vidulich et al. 1991	Piloting tasks	●	●

The psychological approaches are mainly based on the stress-strain concept (DIN EN ISO 10075-1) or the so-called action-regulation theory. Exemptions are the Bedford Scale which relies on the single channel concept, and the Workload

Profile which refers to the multiple resource theory. Consequently, the psychological methods mainly provide information about the feasibility of actions or potential for personality development.

Most of the procedures are analyzed with respect to their reliability and validity. However, only the SWAT, NASA-TLX and the Workload Profile were also tested regarding their sensitivity and diagnosticity (RUBIO et al. 2004).

The number of relevant dimensions of mental stress may justify the assumption that only multidimensional methods are adequate for the measurement of mental stress. Nevertheless, the findings of several studies aiming at the identification of the overall stress level of piloting tasks showed that one- or multi-dimensional methods provide widely comparable results of measurement (HENDY et al. 1993). This finding might be astonishing but corresponds to other experiences in using one-dimensional methods for recording the level of mental stress (SCHÜTTE et al. 1994). Instruments can generate meaningful results as long as the rater is capable to integrate the different stress related aspects in an overall assessment of stress. One-dimensional approaches are especially useful for initial screenings of mental stress (HART & WICKENS 1990). If the measurements are carried out to obtain detailed information about the working conditions multi-dimensional instruments should be applied only. Since all instruments are based on subjective perceptions and evaluations of the respondents, it should be kept in mind that answers are possibly subjected to biases resulting e.g. from the tendency to choose only average rating categories. One way to reduce biases could be to inform the rater about problems in using ratings scales (PFENDLER & SCHWEINGRUBER 1996). Despite the above mentioned disadvantages the application of questionnaires is considered as absolutely essential since it must be assumed that those aspects of working conditions which an employee perceived as stressful in fact represent stressful facets (GOPHER & BRAUNE 1984).

4 Measurement of Mental Strain

Approaches for measuring mental strain can be divided into two different groups. On the one hand physiological parameters are used for recording the intensity and time course of strain. On the other hand questionnaires and rating scales are available documenting the individual feeling with regard to mood, fatigue, effort etc.

4.1 Physiological Methods

The registration of physiological parameters is based on the assumption that they not only provide an indication of the information processing mechanisms involved in task execution but also point to costs and effort during task accomplishment. Initially, one-dimensional models such as the concept of central activation were most popular in this field (LUCZAK 1987). Currently, theories concerning attention are favoured; especially the cognitive-energetical stage model procuring an integrative heuristic for the analysis of mental strain (MANZEY 1998).

Starting from the assumption that mental strain is influenced by processes located in the central nervous system it seems plausible to use strain indicators that cover changes in the activity of cortical or sub-cortical neuronal formations assumed to reflect particular perceptual, cognitive and motor related task demands (MANZEY 1998). While imaging techniques allow for identification of inactive and active brain areas in high resolution regarding space, the registration of the EEG permits the registration of brain activity in high resolution regarding time. Furthermore this approach is well examined concerning methodological problems such as the avoidance as well as detection or clearing up of artefacts. The spontaneous activity of the EEG and differences between the amplitudes of various event related potentials (ERP) are discussed as possible strain indicators.

As regards spontaneous brain activity experimental findings verify that a rise of the frontal-central theta activity correlates substantially with the level of task demands. Accordingly this parameter fulfils the criterion of sensitivity. However, theta activity does not seem to be influenced by a particular kind of task demands. Theta activity presumably represents a more general activation mechanism comparable to the effort dimension of the cognitive energetical stage model (MANZEY 1998).

Regarding event-related potentials the P-300 is presumed to be an adequate strain indicator. The P-300 reflects voltage changes occurring not earlier than 300 milliseconds and above the parietal cortex with an amplitude maximum after the presentation of a stimulus (MANZEY 1998). Indications militating in favour of the sensitivity of the P-300 result from studies based on dual task paradigm. An increase of the demands of the primary task should lead to a decrease of the amount of resources available for execution of the secondary task. Experimental findings are in accordance with these assumptions. If two tasks had to be accomplished simultaneously, the amplitude of the P-300 for relevant secondary task events declined when the demands of the primary task were raised. The P-300 also satisfies the criterion of diagnosticity since the described changes of the P-300 amplitude appeared only if the secondary task is characterized by perceptual and cognitive demands. Even if this parameter permits apparently the recording of mental strain it must be taken into consideration that the analysis is very laborious (filtering and averaging of signals etc.). Additionally this approach is more suited for experiments than for field studies.

Furthermore heart-rate-variability (HRV) was discussed as another promising parameter indicating the level of mental strain, since it could be shown, that the time between the R-waves of the electrocardiogram decreases when task demands increase (KALSBEEK & ETTEMA 1963). Various algorithms were proposed for the calculation of HRV (e.g. LUCZAK 1979; LUCZAK & LAURIG 1973) but techniques of spectral analysis are currently nearly used by default. Three frequency bands could be identified having relation to thermoregulation (0.02–0.06 Hz), blood pressure (0.07–0.14 HZ) and respiration (0.15–0.50 Hz). The performance of mentally demanding tasks lead to a power reduction in all three frequency bands. However, the biggest changes appear in the central band (0.07–0.14 Hz), which accordingly is considered as the best indicator for mental strain. Experimental findings demonstrate that the 0.1 Hz component of HRV differentiates between resting and non-resting conditions only. The component does not discriminate between different levels of task difficulty (JORNA 1992) and is therefore not conform to the criterion of sensitivity. Further results indicate that the 0.1 Hz component presumably reflects variations in unspecific, general activation. This component more likely indicates emotional than mental strain (NICKEL & NACHREINER 2002).

Regarding the human visual system the frequency of spontaneous eye blinks and the pupil diameter are considered as mainly influenced by mental strain. Several experimental findings show that the frequency of eye blinks depends on the difficulty of the particular task. An increase in task difficulty is accompanied by a decrease of the blink rate. The parameter is apparently responsive to different stress levels and can be considered sensitive. Even if the blink rate is unaffected when an auditory task presentation takes place (e.g. CASALI & WIERWILLE 1983), the diagnosticity of this parameter is not completely clarified. It is required to carefully analyze whether a particular task provokes eye movements which are usually accompanied by blinks (HARGUTT 2001).

Similar to blink rate, a clear relationship seems to exist between stress level and pupil diameter. An increase in task difficulty comes along with an increase in pupil diameter (e.g. RÖßGER 1999). This relation occurred irrespective of the particular kind of task. Therefore pupil diameter meets the criterion of sensitivity, but is not in accordance with the criterion of diagnosticity. Based on these results it is assumed that this parameter bear probably upon the effort dimension of the cognitive energetical stage model. The measurement of the pupil diameter requires relatively constant environmental conditions in order to avoid disturbing factors such as difference in illuminance or accommodation processes on pupil size. Accordingly, the method is more suited for experiments than for field studies.

4.2 Methods for Recording the Subjectively Perceived Level of Strain

Measurement instruments recording the subjectively perceived level of strain are part of the commonly used repertoire of methods utilized for the analysis of mental strain. This is because ratings are regarded as the most direct procedures for evaluating the human costs during task accomplishment (HART & WICKENS 1990). Rating procedures are also considered as efficient and as non intrusive in application (PFENDLER & SCHWEINGRUBER 1996, WIERWILLE & EGGEMEIER 1993). The approaches available can be classified in one- and multi-dimensional. One-dimensional methods are based on the assumption that the number of different components relevant in subjective perceived strain can be reduced to a single dimension involved in information processing (BARTENWERFER 1978). Multi-dimensional instruments capture different aspects of mental strain and provide additional information about the structure of subjectively experienced strain.

The effort scale (ZIJLSTRA & VAN DOORN 1985) is a one-dimensional rating procedure which refers to the effort system of the cognitive energetical stage model. The instrument is composed of 7 judgement anchors describing different effort levels (see EILERS et al. 1986 for a German language version). The anchors are scaled according to the magnitude estimation method and possess a satisfying reliability. The validity of the effort scale was evaluated in experimental and field studies using mainly signal detection tasks of different levels of difficulty. Amongst others also time of day and the frequency of critical signals was taken into account (EILERS et al. 1989, EILERS et al. 1990). None of these experiments provided evidence for the validity of the scale. In another experiment on logical reasoning the participants were asked to estimate their experienced effort subsequent to the accomplishment of easy and difficult tasks. The length and the sequence of sections with easy and difficult demands were experimentally varied. As a result, subjectively perceived effort was substantially influenced by the sequence and also the duration of task sections. This finding demonstrates that the effort scale is responsive to different stress profiles (SCHÜTTE 1999). Using tasks of the AGARD-STRES Battery for generating different kinds and levels of mental stress it could be shown, that the effort scale differentiates between low and high stress levels. This result militates in favour of the sensitivity of the effort scale (SCHÜTTE 2001, SCHÜTTE 2002). Nevertheless the diagnosticity of the effort scale requires further investigation.

Regarding the multi-dimensional approaches, the EZ-scale (NITSCH 1974) is a highly frequently used method. The instrument measures the actual general condition of a person with regard to mood. The questionnaire consists of 40 items mapping two dimensions namely the readiness for action (motivation) and the capacity to act (strain), of which are both divided into subscales. Since the actual mood-related state of a person shows fluctuation throughout the day, the reliability of the EZ scale is hardly determinable. The validity of the questionnaire was investigated in several studies. The findings verify that the scale differentiates between relaxed and tense situations (e.g. examinations). The EZ-scale was also used in pharmacological tests; the measurements discriminated between the reference situation (placebo) and conditions with the administration of different doses of a tranquillizer (NITSCH 1976). Furthermore, the EZ-scale maps the strain-related differences between variably organized office work (FRIELING et al. 1979). These results demonstrate the validity of the approach, but more detailed studies concerning the sensitivity and diagnosticity are not available. Since some items of the EZ scale were difficult to comprehend for some raters a modified version of the scale was developed (APENBURG 1986). The reliability (inner consistency) of the modified version reaches satisfying values between 0.80 and 0.92 which are in accordance with measurement precision class 2 ($r \geq 0.8$) respectively 1 ($r \geq 0.9$) according to DIN EN ISO 10075-3. The findings of a study comparing strain of six occupational groups provide evidence for diagnosticity as the groups differ in their average strain level. Nevertheless, studies giving more detailed information about both the diagnosticity and sensitivity of the modified version of the questionnaire are not available.

The questionnaire for measuring fatigue, monotony, satiation and stress (BMS II) was explicitly developed for assessing strain levels during the accomplishment of monitoring and control task performance. The instrument is based on a model assuming that strain during task performance depends on the intensity and level of task demands as well as the individual qualification and habitual particularities of activation (PLATH & RICHTER 1984). In addition the model supposes that strain has positive consequences. Task performance may facilitate learning processes and can lead to (re-)forming of work related attitudes which both improve the psychological regulatory processes concerning task completion and motivation. Negative consequences of strain may also be expected leading to impairments such as fatigue, monotony, satiation and stress. Accordingly, the development of the questionnaire was based on several postulations. The instrument should not only capture negative but also positive conditions of mood. The items should map task demands and the instrument should measure actual mood conditions. The questionnaire should allow for repeated measures resulting in the development of two widely comparable alternative versions of the questionnaire. Each version comprises 10 items for each of the four scales fatigue, monotony, satiation and stress. The method of successive intervals was used for calculating a scale-value for each item reflecting the degree of the particular characteristic the item captures (e.g. fatigue). When applying the method the respondents only have to indicate whether a particular item adequately describes the actual condition of mood (yes / no answer). The individual level of e.g. fatigue will be determined by summing up the scale values of all items answered affirmatively. Subsequently the average value will be calculated. Reliability was assessed by correlations between the two alternative forms of the questionnaire. Based on the post test measurements obtained in various experiments the correlation coefficients take values between 0.77 (scale monotony) and 0.88 (scale fatigue). Taking into consideration the recommendations of DIN EN ISO 10075-3 the reliability of the scales corresponds to precision class 3 ($r \geq 0.7$) respectively 2 ($r \geq 0.8$). The validity of the instrument was proved in several experiments and field studies. The findings verify that the questionnaire discriminates between conditions of low and high stress and also between different kinds of stress. These outcomes militate in favour of the sensitivity and diagnosticity of the instrument. Furthermore it could be shown that an increasing number of failures during task completion goes along with the perception of satiation and stress (in control task settings) and that prolonged reaction times are attended by higher stress and fatigue (in choice reaction time task settings). Field studies verify that a small number of machine operations lead to fatigue. In monitoring tasks or multi operation situations the feeling of satiation and stress dominates. All in all these results confirm the validity of the questionnaire. Furthermore the current level of strain can be compared with threshold values indicating the necessity of work redesign. The BMS II is also applicable during the planning phase of work places since the questionnaire is integrated in the REBA tool (JORDAN et al. 1997).

The BLV measures changes in strain (KÜNSTLER 1980). The approach has the advantage to provide information about an individual strain level and about compensatory behaviour. The development of the instrument was based on the assumption that strain destabilizes the biological equilibrium which a person attempts to restore. Four possible behavioural patterns can be distinguished (1) break off of the particular task, (2) lowering the level of achievement, (3) increase of effort and (4) variation of mode of task accomplishment. The questionnaire comprises in total 46 items which constitute the four scales perceived momentary performance capability, fatigue, tension and achievement motivation. The reliability (test-half coefficient) varied between 0.91 (tension) and 0.98 (momentary performance capability); i.e. above the lower limit of 0.90 as recommended by DIN EN ISO 10075-3 for high precision measurements (precision class 1: $r \geq 0.9$). The validity was proved in a study comparing the measurement results of the BLV with the measurement results of the BMS II. The calculated correlation coefficients take values between 0.31 and 0.68 indicating that the BLV conforms to the criterion of internal validity. Further support for the validity of the instrument is provided by a field study analyzing the strain of air-traffic-controllers in shift time (KÜNSTLER & NELTE 1983). Substantial changes of strain were detectable during night shifts and two different forms of compensatory behaviour could be observed. Some air-traffic-controllers attempted to maintain their reactivity by increasing their tension, despite the existence of fatigue. For the other air-traffic-controllers the experience of fatigue was dominant. This was accompanied by reduced motivation, perceived momentary performance capability and tension symptoms which are typical for the condition of monotony. No studies are available on sensitivity and diagnosticity of the BLV.

One reason for diversity of questionnaires available and their differences concerning strain dimensions could be assumed in procedures chosen for item collection and selection as well as psychometric methods used for scale development. However, this would ignore the fact that strain related dimensions such as fatigue or activation can be identified even if different techniques of data acquisition and analysis methods are applied (HAIDER 1961, HAMPEL 1977, HECHELTJEN & MERTESDORF 1973). It is therefore more likely that the diversity of instruments is due to different theoretical conceptions underlying the questionnaires. The EZ-scale is based on a model that assumes a strong relation between mood and demands as well as motivating elements of a task. The BLV is based on a concept that assumes strain to be the result of complex decision and evaluation processes and provoked by changes in the individual work capabilities. The BMS II is based on a model that differentiates between the subjective representation of task demands and the supporting or impairing consequences. The development of most of the questionnaires was not influenced by models of human information processing. This might have been because in these models performance parameter such as task execution time or the number of failures during task completion are more suited for the determination of the human related consequences of information processing. However, the cognitive energetical stage model (SANDERS 1983) considers strain related dimensions and provides a theoretical basis of only few instruments such as the effort scale. One possible explanation could be that this model seems to be more adequate for experimentally generated simple tasks allowing a precise manipulation of stimulus intensity, signal quality, stimulus-response comparability and time uncertainty.

5 Conclusion

Most of the described instruments are analyzed with respect to their reliability and validity. Regarding strain measures one essential aspect of validity is the confirmation that an instrument is sensitive to both the duration and intensity of stress. Furthermore, there should also be a check of the validity of the statistical decision, the internal and external validity of the experimental design as well as construct validity (NACHREINER et al. 1987). Although there are most often some studies providing evidence for sensitivity and diagnosticity, systematic analyses is mostly missing. However, such an investigation is very important since it provide information about the scope of application of a measurement procedure and is a helpful specification for practitioners looking for an instrument adequate for their purpose of measurement. Furthermore, it should be noted that reliability studies often erroneously assume that the person represents the object of measurement. Therefore calculated coefficients reflect the reliability for discriminating between persons based on the measurements. Only a few studies exist (e.g. SCHÜTTE 2001, SCHÜTTE 2002, SCHÜTTE & NICKEL 2002) reporting the reliability for the discrimination between different stress conditions based on the measurements. One elegant way for determining the person or condition related reliability of measures of stress or strain is the application of generalizability theory (GT; BRENNAN 2001). GT has the advantage to allow for an estimation of the magnitude of multiple sources of measurement error and thus facilitating the separation of major error sources. In G-theory every measurement is regarded as a sample taken from a universe of possible measurements which could have been taken for an object of measurement (e.g. stress level). This universe is named the universe of admissible observations and is characterized by various variables (facets) which represent possible sources of variability in the measured scores (e.g. persons). Each specific instance of a facet is called condition. The application of G-Theory requires two different steps, namely the realization of a G- and a D-study. At first the G-study has to be accomplished. The G-study aims at the estimation of the magnitude of the sources of variability as defined in the universe of admissible observations. Subsequently a D-study (Decision study) has to be accomplished and is based on the results of the G-study. The D-study gives information about the generalizability of the measurements. For that purpose two different reliability analogous parameters can be computed. The so-called relative G-coefficient (ρ^2) indicates on a 0-to-1 scale, how well an observed score is likely to locate the objects of measurement relative to other members of the corresponding population. The absolute G-coefficient (ϕ) indicates also on a 0-to-1 scale how well an observed score is likely to locate the objects of measurement independent from others in the respective population. Furthermore, the D-study provides not only indications concerning the costs required for an application of the measurement procedure (e.g. optimal number of conditions of a facet) but also information about alternative measurement designs bringing about reliable scores. It was criticized that the application of this procedure requires controlled experiments and neglects field studies. G-theory do not exclusively presuppose experiments as also several field studies have been conducted e.g. in the domain of education (GILLMORE et al. 1978). However, if an instrument does not provide reliably measured values in an experiment, testing the method in a field setting can be omitted (NACHREINER & SCHÜTTE 2002).

Some instruments such as SWAT or NASA-TLX (REID & COLLE 1988, COLLE & REID 2005) possess guideline or threshold values indicating whether the strain level has reached a critical level and by that indicating that performance decrements could occur. However, the proposed values give no information about the admissible stress level and duration. Future research should therefore establish critical or threshold values to provide an orientation for human related criterions of work design.

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31 Ergonomics and Human Factors: Methodological Considerations About Evidence Based Design of Work Systems

Kamiel Vanwonterghem

1 Introduction

1.1 Ergonomics and Human Factors

Ergonomics – or human factors – concerns the scientific discipline about the interactions between humans which are active in a system. The terms refer also to the profession that applies theory, principles, data and methods to design overall systems (IEA 2000).

The objectives of ergonomics/human factors are generally accepted as optimizing the human well-being and the overall system performance. More precisely, it aims to preserve, to protect and/or to improve the quality of life of humans, determined by their health, safety, well being as socio-economic status. Simultaneously the discipline must respect the needs of industry and society, respectively by "efficiency" of production processes, the economy and the management of socio-economic consequences.

Although these objectives are unanimously accepted, the ways to reach these goals may differ considerably creating some confusion, mainly by those who are not actively involved in the issue. In this context, the term "ergonomics designed" is abusively used in many cases because it may refer to an expectance of offering a valuable quality label for goods, tools and equipment, fulfilling the original set objectives.

The scientific efforts done in the past for establishing basic rules, directives, methods and techniques for correct designing work-systems merit a much higher appreciation than the simplified commercial and marketing content.

The research projects, initially based on a fully justified feed-back analysis to find causes leading to injuries and diseases, technical breakdowns, absenteeism and other socio-economic facts, started with rather uni-disciplinary approach. This was necessary to obtain short-term results by interrupting the effect-cause relations by developing technical – collective and individual – protective means. Almost simultaneously also health issues were tackled: cardiac and thermoregulatory exhaustion, respiratory protection and protective means against harmful and toxic

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substances, were developed and reduced considerably the gravity of accidents and professional diseases.

At present, due and thanks to the evolution of processes (a result of all efforts done in the past) most of the obvious risks of direct "cause-effect" injuries and diseases are mostly solved but changes occur also in the nature of injuries and diseases.

In the pre-2000 era, ergonomics could be seen as a complementary supplier of ideas and solutions for "fitting the job to the worker" and this will go on in the future for all jobs in which the human factor is involved.

However, the complexity of the industrial, economical, socio-economical growth and globalization requires a pluri-disciplinary, integrated and anticipating approach to cover the complexity of the activity-systems.

From this point of view, new challenges occur and it is obvious that also ergonomics/human factors has to evolve in order to face the changes in the work-related risks and to enter the contemporary market as a fully fledged, valuable and efficient economic as socio-economic discipline.

It may be expected that ergonomics/human factors evolves from a supplier of ideas in design to the different disciplines towards a globalizing and coordinating discipline in the new era of industrial development.

1.2 Background Question Marks

In order to harmonize the scattered approaches of the different disciplines the following premises have to be taken into account: anticipating prevention, fundamental-applied research, collective-individual, objective-subjective criteria, design and re-design, participative aspects in the social structures (management, authorities, employees & representatives), financial aspects (economics and socio-economics), etc. which all are entering in a integrated system in which the interrelations are variable and unstable.

Prevention: the classic "effect-cause" feedback method in which the occurred injuries and diseases could be directly and immediately linked to a series of causal factors, should be completed with an anticipating strategy of recognizing risk announcing pre-signs. The retro-active analysis is still valid for accidents, but is not appropriate for a series of consequences which now are classified as CTD's, the "cumulative trauma disorders". The effects are observed after a long incubation period (months to years), and although there might be some sudden causal factors (e.g. lifting materials causing a hernia) the real cause is a slow installing poisoning (cumulative fatigue and no full recovery) of the biomechanical system. Studying the indirect causes such as fatigue (general, local, physical and mental) has to be recognized in an early stage and, when exceeding some "load" thresholds, appropriate measures should – depending on the seriousness of the risk – be developed in short or medium term. Example: a CTS (carpal tunnel syndrome) show some pre-signs after months and may require a surgery after being diagnosed after 6–8 years. (VANWONTERGHEM et al. 2004)

Fundamental – applied research: the position of strict academic or pure research is weakened for many reasons and not the least for the financial aspects of projects (OOSTERLINCK et al. 2002) whereby the return from industry to university became quite obvious (HALL & SCOTT 2001). The fast evolving technology linked to the working conditions for humans requires flexible and short term evidence based research projects, because a fundamental study of specific risks is time consuming and, by the time conclusions are formulated, the nature of risks in the conditions may have changed already.

Despite this phenomenon, fundamental academic research will still be needed because the applied sciences will look for answers to specific evidently occurring risks tackling the psychosomatic human structure. Furthermore, a scientific solid founded confirmation of practical implementations is necessary in a sustaining policy but, because of the economical requirements (return-on-invest) the application of proposals has to be evaluated and re-evaluated within a decent period in order to be accepted by management.

Essential in any innovating development is the free flow of knowledge acquired by a proper mix of basic and applied research (OOSTERLINCK et al. 2002) respecting the property rights and confidential character of the human related results.

Collective – individual: the inter- and intra-individual characteristics of the operators involved have to be considered in both types of studies because it concern a group of end users in more or less identical working conditions.

High performing statistics about predictability, reliability and valuation should answer the needs for groups of people performing the same tasks and work-related features should take into account the standard distributions covering as much as possible the human potentials. Age, gender, experience, physical, physiological, mental and intellectual capacities create a fuzzy-set database which should be analyzed to conclude for comparable clusters of characteristics for which common guidelines, directives and technical facilities could be developed.

The individual reactions to work-related factors are quite variable, different in nature, in evolution as in time and therefore difficult to keep under control. However, when being part of a minor – possibly estimated as a negligible – standard deviation in a collective multi-factorial cause analysis, this may lead to a crucial human error causing casualties.

Objective-subjective: along the discussion about scientific approaches, the aim to anticipate the risks faces the fact that – after all – the scientific knowledge based on objective criteria is limited. Furthermore, due to “subjective” behaviour determining factors of the exposed employees, the predictability of any strategic measure is the confronted with uncertain significance level.

In order to formulate a reliable prognosis, the subjective criteria have to be taken into account (SOLOMIN et al. 1987). They emphasize the essential participative character of an ergonomic approach. In almost all cases every objective fact is preceded by "complaints" although the subject is unable to make the link between "feelings" and the ultimate disease or injury (SLOVIC et al. 2004).

It is obvious that in collecting the subjective as objective results are subject to the respect for the individual rights and both categories of information have to be used in a confidential way under medical secret. Globalizing information and results have to be handled anonymously.

Social climate & structure: the participatory approach requires an open mind and policy of the management, employees and social partners in the enterprises. The conflict model – as an outcome of the industrialization – fed by the opposite interests of employers, employees, their representatives and the authorities created some communicative barriers, which in the new approach have to be abolished. A climate of mutual respect and an open-mind communication about the objective and subjective criteria characterizing workload and strain, is an essential condition in the contemporary participative ergonomic principles.

The introduction of job-problem-related circles should be encouraged in profit of all: for management, authorities and the social security system being confronted with the high compensations. An active participative approach may open new pathways for dialogue in order to keep the huge costs for absenteeism and turn over under control.

For employees and their duty/rights-defending organizations, priority should be given to working conditions and quality of life, because it concerns their own health, safety and well-being as it contributes to secure job satisfaction and employment.

For the society, a bottom-up evidence based climate which includes the workers experiences, will – throughout the social structure and both fundamental as research – answer the needs for short- and long-term problem solving by an efficient, modern and "up-to-the-point" prevention.

2 Assessment Methods

2.1 Basic Considerations

In order to screen problem in a man-at-work system, many attempts have been made to obtain an appropriate assessment system.

The first outcomes concerned "checklists" including a certain number of the objective work- and task related factors. The AET (Arbeitswisschenschaftliche Erhebungsverfahren zur Tätigkeitsanalyse, ROHMERT & LANDAU 1979) is possibly the most complete checklist for which the necessary scientific backgrounds can be found in “Arbeitswissenschaft” (LUCZAK 1993). Many others, more specific oriented to industrial activities were developed.

Although the most valuable checklists were successfully used in the evaluation of the work-related factors (task, organization, environment) and the possible impact on the basic human biomechanical and psychosomatic system), the analytical – rather technical – approach evaluated the factors separately and sequentially, overlooking the inter-factorial relations and integrating aspects.

These methods allow to detect critical levels of scientific developed and set health risks, but do not always cover all human behavioural and functional aspects. Their value is pertinent for what concerns real health and safety threatening thresholds of which the predictability and probability has been proven.

This means that other factors may affect and undermine the predicted outcomes such as the possibility to escape the damage, the seriousness of damage, the duration of exposure, the type of activity, the intrinsic capacity or loss of capacity, etc., or to neglect other less obvious but important risks. For example: a noise level of 85 dB(A) will – depending on the exposure time – impair the operators hearing capacity. An as safe exposure level of 70 dB(A) may affect the intellectual work quality and mental concentration which may lead to committing serious errors.

The reliability of risk perception is an individual matter and, depending on the control level of respecting the standards or rules, the interpretation often leads to the easiest solution. The more the risks are doubtful in their outcomes, the more the chance that exposed employees will deny the prescribed advises.

For these reasons, the knowledge of risks and the awareness of the exposed subjects must be increased by ad-rem, realistic and evidence based facts, integrated in an overall approach.

There is only ONE single instrument which integrates all important factors and which translates the outcomes immediately in a operative behaviour: the human operator.

2.2 The Ergonomics Approach

The stress-strain model integrating the external work-related factors with the intrinsic human capacities seems to be the most appropriated method. It combines the external work-related load factors (stressors) with the direct individual reactions (strain). It is based on the system principles (VON BERTALANFFY 1951, SELEYE 1956, KEYSERLING & CHAFFIN 1986, LAURIG 1990), and focused on the system components: “work load” and “capacity”.

It is assumed that when there is an equilibrium between the job demands (task, organization and the physical as biomechanical environment) and the individual capacity (psycho-mental, physiological, biomechanical and sensorial) that the system functions in an optimal way respecting both the economic as socio-economic requirements and the human integrity.

The system, as presented in Fig. 31.1, shows the close loop of the integrated system in which workload is composed by the external factors – also determined in the checklists – which are compared to the human intrinsic functional capacities reflecting an eventual unbalance.

The comparison with set thresholds – at present empirically developed – indicate in which domain of the human structure risks may occur. It can in the physiological functions (such as in cardio-respiratory overload, muscle-load,…), in functional failings (e.g. loss in grip force, slower reaction times, …) in psycho-mental processes (drowsiness, alertness, overload in information processing, …) in behavioural reactions (piling up errors, omitting elementary signs, …) as in the subjective experienced load. The latter can result in complaints of undefinable ranges of general as local fatigue, in different levels of hinder, annoyance or pain, in annoying feelings such as tingling members, etc …) sleep deprivation, burn outs, etc …

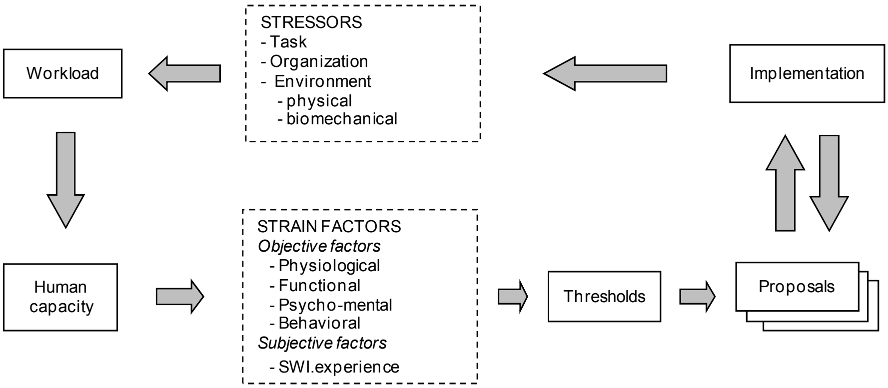

Fig. 31.1: Stress-strain model

2.2.1 Objective Strain Factors

The use of the human being as an assessment tool is now under full development. Where older techniques as measurements of heart rate, energy expenditure, body temperature and weight loss, were indicating the interest of combining the stress factors with the reactions of the exposed operators, basic research brought a boost in technology development. Already available for a series of physical environmental items, now new technology opens new pathways towards neurophysiologic strain factors. Portable devices, wireless facilities and appropriate software offer online possibilities to measure and to analyze strain factors during the task performance.

The result of joining academic and applied research brought new strain characterizing elements. Heart rate evolves to heart rate variability (HRV), estimated as an indicator for mental strain (NICKEL & NACHREINER 2003). Muscle activity moved from EMG-signals of large muscle groups to smaller muscles allowing to assessment visual perception (Electro-oculography) are still feeding research

(NIELSEN et al. 2008). These are linked to specific risks occurring in daily life for asks which lead to a hypo-vigilance (lack of solicitation) such as monotonous tasks (control rooms, train conductors and truck drivers during night driving) or hyper-vigilant tasks as it may occur in air traffic controllers and truck drivers in busy traffic. (VANWONTERGHEM & VERBOVEN 1988, CABON et al. 1993).

Also the registration of potentials of brain working (EEG-Electroencephalography) belongs now to the new scientific possibilities for brain fatigue assessment and are used to determine the levels of vigilance and/or drowsiness in concentration required tasks (LAL & CRAIG 2000) and in learning processes (STICKGOLD et al. 2000).

A specific aspect of neurophysiological results concern the huge differences in inter- and intra-individual reactions which are complicating a correct evaluation. When using absolute data, it is almost impossible to have a correct workload assessment. (For example: what is the value of a heart rate of 125 for 2 subjects of the same gender, same age, same body weight of which one has a more sedentary life and the second pays lots of time in doing sports?)

In order to attenuate this phenomenon, for each individual the absolute data are transformed into a "relative" weight – mostly expressed as a percentage – by putting the absolute data in perspective of the rest- and maximal acceptable values.

For each of the factors empirical thresholds have been developed to indicate the risk level on short, medium and long term, which requires consequent improvement measures.

2.2.2 Subjective Experienced Strain

Many questionnaires have been developed in the past or are still under development to include the subjective experiences of operators. Most of these are referring to the expression of the fatigue-level. About 45 years ago (BORG 1962) published already a first proposal to assess the "perceived exertion" which are now better known as the Borg-scales indicating the subjective ratings at different physical efforts, either in a 15 point (6–20) or 11-point (0–10) CR-scales (category-ratio scale) (BORG 1970). These have been followed by an uncountable series of other ratings in trying to objectify the subjective feelings, especially for – at that time – non-measurable aspects. Mental load issues were evaluated by derived Borg scales for specific jobs such for pilots by means of the Bedford Scale (BEDFORD & ELLIS 1990) or SWAT (Subjective Workload Assessment Technique) (REID & NYGREN 1988) and to check the effect of duration on srain by the Subjective Assessment Index (MITSUGU et al. 2001).

These methods have all their merits mainly as theoretical backgrounds explaining the level, but when discussing with the employees about the impact on their working conditions, the subjects/operators did not recognize their specific complaints nor in the final outcome of the research project, nor – if ever formulated – in the improvement measures.

In order to answer some of their expectations, the Subjective Workload Index (SWI) was designed emphasizing the participatory character of the exposed subjects (VANWONTERGHEM 1985).

The SWI is composed of some factors which are estimated as "creating workload" and giving annoyance, discomfort and problems from fatigue, risks, concentration, complexity, responsibility and work rhythm. On the other hand, they revealed 2 compensating factors (autonomy and interest in the job). Both, negative as positive factors, are evaluated on an 11-point scale (as in the Borg CR-scales) and calculated by averaging the scores. The reliability has been scientifically validated by comparisons with physiological results (heart rate and body temperature).

The main objective of SWI was and is to formulate concrete proposals to improve recognizable critical factors. Two fundamental factors of workload were added: (a) the task-composing operations and (b) duration of each operation.

In this context, each of the 8 factors of the general SWI can be evaluated per operation. When an operation is indicated as critical (for example score > 5) reference is made to the job-specific external factors (posture, movement, climate, lighting, noise, vibrations, air quality and dust, organizational aspects).

The influence of duration of each operation is obtained by pondering the scores over the exposure time.

The normal sequence is then (1) determine SWI for the total job, (2) complete list of operations and give for each the time constraint (in min or in % or total time) (3) refer back the load-composing factors, and (4) indicate which part of the body is mainly involved.

The advantage of using the SWI is that there is a direct link between job-related factors (workload), the participatory expression of problems (subjective criteria) eventually completed with objective reactions (neurophysiological or functional measurements).

2.3 Ergonomics in Practice

The evidence based character of ergonomics emphasizes the need to concentrate its actions on problem solving. It may be assumed that any problem occurring in a holistic system will affect all partners involved and only a common strategy can become successful.

The impact of absenteeism, turnover rates and unemployment due to accidents, diseases and interrupted production on management, employees and on the society can be translated into direct and indirect costs. This allows to conclude that an anticipating prevention will be profitable for all and that a "return-on-invest" – if the problem is tackled correctly – will become quite obvious.

An anticipating prevention should go along with a statistical processing of negative cases by an analytical study of pre-signs, mostly expressed by complaints of the human beings involved. An ad hoc structure should be set up in the organization. Suggestion boxes and communication throughout the social structure in the system are extremely useful in a bottom-up approach and will avoid disturbances in the top-down decisions.

From the most important problems a selection based on frequency and seriousness is normally analyzed in the following steps:

- Subjective Workload Index: general, and if necessary in detail: selecting critical jobs and operations, followed by establishing a priority list
- Ergonomic analysis of the workstations
  - External load: tasks, organization and environment: description and measurement of the workload related factors
    - Full tasks analysis: frequency, speed, tools, equipment, materials (shape, weight, ...) quantitative and qualitative requirements
    - Describe organization: work-rest schemata, team work, shift work, materials flow (supply-removal), ...
    - Measure environmental physical factors (climate, noise, vibrations, light, air quality, ...) and the biomechanical aspects of workstations (reaching distances, heights, depths, ...)
  - Strain assessment:
    - General physical fatigue: heart rate and calculation of the relative value (%CVL, cardiovascular load)
    - Local physical fatigue: muscle-load for the parts of the body involved in the task accomplishment (%AEMG)

    These include: determination of resting values, the maximal allowable limit and the relative ratio of load
    - Subjective experiences in relation to the measurements
- The comparison with the empirical developed thresholds:
  - Cardio Vascular Load CVL
    - < 30% CVL do not ask for immediate measures. There is no significant cardiovascular fatigue
    - >30 CVL < 60%: moderate load: envisage measures on long to medium term: check most important operations
    - > 60%: heavy load: develop measured on short term, analysing all operations
  - Average muscle-intensity (Electromyography) AEMG
    - < 10% AEMG no specific local fatigue risks
    - > 10% AEMG < 30%: moderate muscle fatigue: envisage measures on long to medium term
    - > 30% AEMG: severe muscle load: envisage measures on short term

- Subjective ratings: SWI
  - SWI < 2: no particular complaints, however, check the compensating factors and if these are > 7 averaged: check operations assessment
  - SWI >2 < 3.5 moderate complaints: envisage job analysis and try to implement improvements on medium term
  - SWI > 3.5: serious complaints: full job-analysis and measures on short term

The measures for improvement should be carried out by referring of the threshold passed operations and references to the job-related parameters. Before implementing definitively the improvement, it is advised to perform a re-evaluation (following the same techniques as in the risk assessment). If necessary re-adjust or re-design the proposal.

3 Results

The method has been successfully implemented in mainly 3 types of applications: consulting studies, applied and fundamental research.

Consulting: about 200 workstations in the last 10 years have been screened in all kind of activities as administrative tasks (office work, VDU work, control-stations in brewery, nuclear power plants, air traffic control, etc...) in manual handling tasks (different jobs in the heavy industry (coal mining, metallurgy, agriculture, construction) and material handling in an uncountable amount of manufacturing, packaging, assembling, food industry, textile and garment, ... In average each screening takes about 3.5 days, including a re-evaluation of the modified system.

Applied and fundamental research have been carried out in Europe and in developing countries were related to specific needs and problems such as machine design (in mining, construction, bus driver-cabins, personal wagons in underground mining), designing of control rooms (nuclear power plant control, brewery, coal-washery, etc.) or in studying specific risks. The mixture applied/ fundamental concerned a series of topics as heat stress and thermoregulation (fire brigades, glass-foam industry, steel, mining, tropical activities as agriculture, construction and manufacturing, noise and TTS, lighting and air quality. MSD, RSI (repetitive strain injuries) in micro-electronic assembling, food, retail, automotive wiring, finishing operations etc., and specific LBP (low back pain) cases in transport and material handling were mainly studied in the last 10 years. The average duration of applied research projects was about 1.5 years (+/– 6 months) and for fundamental research as thermoregulation and development of a thermal index for mine-rescuers, determination of muscle load thresholds (electromyography) and the use of electroencephalography in information processing tasks (e.g. air traffic control, visual work VDU and lighting) about determining signs of over-load, monotony and drowsiness) took in average 2 years (+/– 9 months).

As a spin-off of the projects, training and educational programs were developed and opened for health and safety practitioners, engineering and designersat two levels: BSc level for Ergonomics Technicians and a post-graduate (MSc-level) for ergonomics-human factors project managers.

3.1 Project Example

The full methodology was used in a two years CRAFT- research project in the 6th Framework Program of the European Union about the risks of musculoskeletal disorders (MSD) in SMEs. Three EU-member states (Belgium, Italy and Spain) participated in a wide range of activities at about 48 different workstations: furniture, crystal finishing, construction, and steel processing.

In a furniture manufacturing and assembling SME, the level of absenteeism and days lost due to MSD reached a critical level, spoiling the social climate and the production efficiency.

In the project the chronologic sequence from SWI, selecting the most critical workstations, full analysis and concluding about proposals were discussed and implemented. This resulted in an almost immediate effect on frequency and gravity rates.

The basic results of the number of absenteeism cases were these of the year 2001 and the project started in 2002 ending mid 2004 and an improvement could already be seen during the project (Figs. 31.2 and 31.3). Possibly the figures could be biased by the frequent presence of the research team in the factory, but there was on ongoing improvement trend in the 2 years after the project.

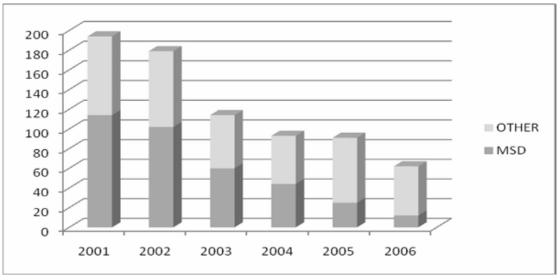

Fig. 31.2: Frequency (N-cases) of absenteeism 2001–2006

Furthermore the improvement was more explicit in the MSD cases, proving that the investments has a positive effect on the frequency of cases.

The return on investment is then more emphasized by the number of days lost and these are not only the effects of the MSD oriented measures but also more general interventions about the working conditions, such as rescheduling the product flow in the factory, the quality of transport lanes, etc…

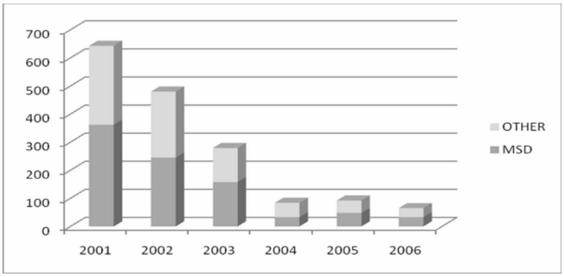

Fig. 31.3: Working days lost (N-days) 2001–2006

The trend in lost days is even more spectacular than the frequency and the profit of lower lost-days rate, justifies all investments during the project.
For both parameters frequency and gravity, the sustaining impact of the research project on the MSD cases and on the total loss reaches a normal risk level for this type of industrial activity.

4 Conclusion

It would be too optimistic to transpose these results to other industrial activities because each factory, each workstation and each project is different in nature. The fact to have information which is acceptable for management and employees (understandable, reliable and job-oriented and thereby appealing to both categories) may stimulate the development of further assessment methods and implementation of the holistic stress-strain model.

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32 Comparison of Ergonomic Risk Assessment Methodology with an Example of a Repetitive Sawmill Board Edger Occupation

Shrawan Kumar, Troy Jones

1 Introduction

In 2003 a comprehensive workers compensation board data set was reviewed to identify and describe injury and illness trends in the Sawmill industry of Alberta, Canada (JONES & KUMAR 2004a). During the period reviewed Musculoskeletal injuries (MSIs) accounted for 33% of the total cost and 38% of total time lost due to claim, more than any other injury category. MSIs in the upper extremity resulted in 1698 Workers Compensation Board Claims, more than any other body region. Given the impact of MSIs on the sawmill industry, prevention has become a primary focus of health and safety programs. Despite the role of physical exposures in the causation of MSIs having been established, specific cause effect relationships remain elusive (US DEPARTMENT OF HEALTH AND HUMAN SERVICES 1997). Due to the absence of specific cause-effect relationships the practice of industrial MSI prevention relies heavily on the application of peer-reviewed ergonomic risk assessments which reflect the guidelines of international health and safety organizations.

Little agreement currently exists between authors as to the best ergonomic risk assessment methodology (JONES & KUMAR 2004b). A key issue affecting our ability to examine the properties of ergonomic risk assessments in the past has been the accuracy and reliability of physical exposure information collected via observation (LOWE 2004). Reliable measurement techniques capable of quantifying physical exposures are now available and thus an examination of the properties of risk assessments may proceed.

Very few studies have been performed which compare the results of multiple risk assessment methodologies to gain insight into the properties of the assessments (DRINKAUS et al. 2003, BAO et al. 2006, JONES & KUMAR 2007). The quantification of physical exposures in two facilities with differing historical rates of injury allows the sensitivity of the assessments to differing levels of risk to be examined. Only JONES and KUMAR (2007) have sought to determine if risk

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assessments could differentiate between facilities with differing incidence rates in a repetitive job. Several definitions of posture and exertion, and thereby their calculation, are available to work site evaluators performing observation based exposure assessments. The quantification of physical exposures in this study allows the equivalency of several definitions of the posture and exertion variable, assumed equivalent in observation based exposure assessments, to be examined. Only JONES and KUMAR (2007) have sought to examine the effect of multiple variable definitions on risk assessment output. For these reasons this study seeks to: (1) compare the results of five commonly used ergonomic risk assessments (2) examine the ability of the risk assessments to detect differences in level of risk between facilities (3) examine the effect of different posture and exertion variable definitions and their calculation on risk assessment component and output scores.

Risk assessment methods compared in this study are the; Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), the American Conference of Governmental Industrial Hygienists Threshold Limit Value for mono-task hand work (ACGIH TLV), the Strain Index (SI), and the concise exposure index (OCRA) (MCATAMNEY & CORLETT 1993, MOORE & GARG 1995, COLOMBINI 1998, GRIECO 1998, OCCHIPINTI 1998, HIGNETT & MCATAMNEY 2000, UNIVERSITY OF MICHIGAN 2005).

"Risk index" in this study refers to a risk assessments' raw score output before that score is grouped and interpreted. "Risk level" refers to the groupings of risk index scores which are interpreted into action levels etc. by the authors. The board edger job was selected for evaluation in this study given the high number of upper extremity musculoskeletal injuries recorded in the 6 years of the review. Average annual incidence of recordable musculoskeletal events in the board edger operator ranged from 0.22 (facility A) to 1.33 (facility B) per person year worked in the period examined. The analyses performed in this study make use of the physical exposure information previously collected in 14 industrial subjects using surface electromyography and electrogoniometers (JONES & KUMAR 2006).

2 Methods

2.1 Task Description

The board edger job is a repetitive job responsible for sorting boards cut in rough depth dimension immediately after logs have been cut to square dimension and divided into multiple boards. Sorting of the boards involves frequent "flipping" (turning about the long axis) of boards to position the board with the round side (cant) up for further processing. Turning boards is the primary task of the board edger however, he/she may also be required to push, pull and lift boards to cause them to fall to conveyors below. Width and length of boards at this early stage in production vary by dimension of the log processed.

2.2 Subject Selection

Workers presently performing the board edger job between the ages of 18 and 65 were recruited at two sawmill facilities. Subjects were excluded from the study if they reported; injury to the upper extremity within the last 12 months, generalized musculoskeletal or neuromuscular problems, or the inability to understand and follow instructions. The experimental protocol was approved by the University health research ethics board. No female workers were present at the two facilities examined. 16 male subjects volunteered to take part in the study out of the population of 16 (100% participation rate). Complete data sets enabling analysis were collected for 14 of 16 subjects.

2.3 Data Collection

2.3.1 Motion Data Acquisition

Motion at the wrist was assessed using two pre-calibrated electrogoniometers placed on the wrist and forearm reported by the subjects as used primarily to turn boards as described JONES and KUMAR (2006).

2.3.1.1 Posture

Postures required to perform the board edger operator job were defined based on three criteria. The peak excursion was defined as the maximum excursion observed during the entire sample in the respective plane of motion (e.g. flexion or extension). The peak excursion represents the maximum excursion observed and may not have taken place during a repetition of the primary task (turning boards). The repetition average posture was defined by randomly selecting 10 repetitions (board turns), recording the maximum deviation in the plane of interest (e.g. radial and ulnar deviation), and averaging the values in each subject. Finally, the overall average posture reflects the average value observed considering all motion taking place in the defined plane of motion during the sample. In the cases where body regions other then the forearm and wrist are considered (REBA, RULA, OCRA) only the postures of the forearm and wrist vary from peak excursions in the posture variable comparisons.

2.3.1.2 Duty Cycle

The percentage of the sample where the worker was active as opposed to inactive was determined by defining periods of inactivity as those periods greater than 1.2 seconds during which there is less than a 5° change in posture in each of the 3 planes assessed concurrently and no force application. Duty cycle was defined by dividing the active component of the sample by the total sample time and multiplying the value by 100.

2.3.1.3 Frequency

Repetitions performed during the sample were determined by defining a repetition as indicated by a change in direction of motion of at least 18° (setting observed to best differentiate between repetitions of primary board turn task) at the proximal radio-ulnar joint (pronation/supination). Pronation/supination was used to define repetition due to its cyclical nature in performance of the job (board turning) and clear repeated trace as recorded by the analysis system used.

2.3.2 Exertion Data Acquisition

2.3.2.1 Percentage of Maximum Voluntary Contraction

Surface electromyography (EMG) was used to determine the muscle activity associated with maximum voluntary contractions and job simulated exertions as described by JONES and KUMAR (2006). EMG trails were performed in a location removed from the production line (i.e. coffee room). The average value resulting from the muscles assessed during the job simulated flexion trial and the job simulated pronation trial were divided by the peak EMG values obtained on the MVC comparisons to arrive at % MVC required to perform the task components (flexion and pronation). The task components were then averaged to derive %MVC required to perform the primary (board turn) task.

2.3.2.2 Psychophysical Measure of Exertion

Following data collection during job performance workers were asked; "whether during the cycle there were job actions that required muscular effort of the upper limbs?" Workers were then asked to rate the actions from one to ten using the Borg CR-10 scale (BORG 1982). Borg ratings were then averaged and used in the ACGIH TLV, SI and OCRA assessments.

2.3.2.3 Dynamic Force Applied

Dynamic forces required were used as the exertion variable in the RULA and REBA methods. Dynamic force required to turn the representative board was calculated assuming the boards were of uniform density and the axis of rotation was along the edge of the board. The inertial component of the force required was calculated using the average acceleration recorded.

2.4 Data Analysis

Non parametric statistics were used in this study to examine whether statistically significant differences existed between distributions of interest. Non parametric statistics were selected given the assumptions of corresponding parametric statistics (e.g. normality of distribution, equality of variance, large sample sizes) could not be met. The non-parametric Mann-Whitney U test (alpha level 0.05) was used to determine if significant differences existed between facilities on risk assessment output scores (component, combined component, risk index, risk level). The Wilcoxin signed ranks test (alpha level of .05) was used to test whether significant differences existed between risk assessment scores derived using alternate posture and exertion variable definitions. Mean values are used as measures of central tendency in this study. The measure of central tendency most sensitive to the distribution as a whole (including outliers) was selected given the variability of scores within populations of at-risk workers has not previously been described.

2.5 Risk Assessment Methods

Risk indexes were calculated according to the primary literature describing their application (MCATAMNEY & CORLETT 1993, MOORE & GARG 1995, COLOMBINI 1998, GRIECO 1998, OCCHIPINTI 1998, HIGNETT & MCATAMNEY 2000, UNIVERSITY OF MICHIGAN 2005).

3 Results

3.1 Incidence of Upper Extremity Musculoskeletal Injury

Alberta Workers Compensation Board data indicated an average 148 successful claims were incurred annually across the 6 years examined (1997–2002) in the occupation groups containing the board edger operator job. Calculation of incidence rates across the sawmill industry of Alberta Canada is not possible as no agency collects information of sufficient resolution on the entire workforce. Mean incidence rates in the board edger job calculated based on person year estimates from the two facilities was 0.22 (facility A) and 1.33 (facility B) recordable musculoskeletal upper extremity incidents per person year in the period examined.

3.2 Subject Characteristics

The mean age of subjects was 33 (SD = 6.3 years), mean height of subjects was 178 cm (SD = 6.1 cm), and mean weight of subjects was 88.7 kg. (SD = 13.4 kg). Mean work experience at the board edger job at time of assessment was 3.3 years (SD = 2.1 years).

3.3 Risk Assessment Methods

Mean risk level assigned by risk assessment method as a percentage of maximum is illustrated for the reader in Fig. 32.1.

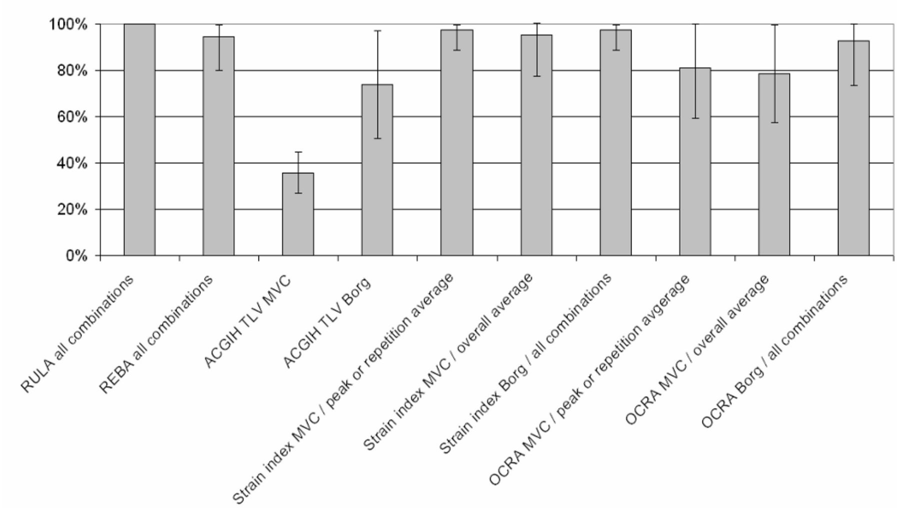

Fig. 32.1: Mean risk level as percentage of maximum by risk assessment method

3.3.1 RULA

3.3.1.1 Between Facility Comparisons

No variation was observed between subjects or between facilities in either RULA index or risk level scores (risk index 7, risk level 4). The lack of variation in RULA risk index and risk level scores indicates that the RULA assessment was not sensitive to differing levels of risk between facilities. Certain RULA component scores were able to differentiate between companies however. RULA posture scores specific to the neck, trunk, legs and upper arm (shoulder) were significantly different between facilities ($p<.05$). In addition combined upper extremity posture score, combined trunk/neck/leg score and the integrated trunk score (RULA score D) were significantly different between facilities ($p<.05$). These results indicate that components of the RULA methodology are sensitive to inter-facility differences however final risk output was not. Table 32.1 describes the RULA scores calculated with dynamic force and peak postures.

3.3.1.2 Within Methodology Comparisons: Effect of Wrist and Forearm Posture Variable Definition

Substituting overall average posture for peak or repetition average postures resulted in significantly different combined upper extremity posture scores ($p<.01$) but had no affect on risk index or risk level. Substitution of overall average scores for peak postures reduced combined upper extremity posture scores in 12 of 14 subjects by an average of 18%. Substituting overall average posture scores for repetition average scores reduced scores in 10 of 14 subjects by an average of 19%. Upper extremity component scores were sensitive to changing posture variable definition, and hence its calculated value, but did not impact the final risk output scores. These results indicate it is likely that had all body segments considered by the RULA methodology been measured by quantified means (allowing multiple definitions of posture to be applied to all regions) final output scores would have been influenced by posture definition chosen.

Table 32.1: RULA scores calculated with peak postures

	Component scores							Combined component scores									Risk output scores	
	Posture Trunk/Neck/Legs			Posture Upper extremity				Trunk/Neck/Legs				Upper extremity					Risk index	Risk level
	Neck	Trunk	Legs	Upper arm	Lower arm	Wrist	Wrist twist	Posture	Muscle	Force	Score D	Posture	Muscle	Force	Score C		Grande score	Risk Level
Mean	4	4	2	4	3	4	1	7	1	3	11	6	1	3	10		7	4
SD	1.5	1.2	0.5	0.8	0.4	0.0	0.5	2.0	0.0	0.0	2.0	1.2	0.0	0.0	1.2		0	0
Min.	2	1	1	3	2	4	1	2	1	3	6	5	1	3	9		7	4
Max.	6	5	2	6	3	4	2	9	1	3	13	9	1	3	13		7	4

3.3.2 REBA

3.3.2.1 Between Facility Comparison

REBA risk index scores were significantly different between the facilities examined ($p<.01$) indicating the REBA assessment was sensitive to differing levels of risk between facilities. REBA risk level scores did not differ significantly between facilities examined. REBA component scores able to differentiate between facilities were the posture scores specific to the trunk, legs, upper arm, and the REBA activity score ($p<.05$). Combined scores able to differentiate between facilities included the combined upper extremity posture score, combined trunk/neck/leg posture score, the integrated upper extremity score (score A), the integrated trunk/neck/leg score (score B) and combined body segment score (score C) ($p<.05$). Table 32.2 describes the REBA scores calculated based on dynamic force and peak postures.

3.3.2.2 Within Methodology Comparisons: Effect of Wrist and Forearm Posture Variable Definition

Substituting overall average postures for peak or repetition average postures resulted in significantly different upper extremity posture scores ($p<.01$) but had no effect on risk index and risk level scores. Substituting repetition average postures for peak postures resulted in no change in combined upper extremity posture scores. Combined upper extremity scores were reduced in 10 of 14 subjects by an average of 15% when overall average postures were substituted for peak or repetition average postures. Similar to the RULA assessment REBA results indicate it is likely that had all body segments considered by the REBA methodology been measured by quantified means (allowing multiple definitions of posture to be applied) final output scores would have been influenced by posture definition chosen.

Table 32.2: REBA index calculated with peak postures

	Component scores						Combined component scores								Risk output scores	
	Trunk/Neck/Legs			Upper extremity			Trunk/Neck/Legs				Upper extremity			Multiple body part	Risk index	Risk level
	Trunk	Neck	Legs	Upper arm	Lower arm	Wrist	Posture total	Force	Score A	Posture Total	Grip	Score B	Score C	Activity score	Grand score	Risk Level
Mean	3.9	2.4	1.7	4.2	1.9	3.0	5.9	1.8	7.7	7.1	1.0	8.1	10.1	1.7	11.8	3.8
SD	1.23	0.65	0.47	0.80	0.36	0	1.98	0.43	2.27	1.07	0	1.07	2.20	0.47	2.55	0.58
Min.	1.0	1.0	1.0	3.0	1.0	3.0	1.0	1.0	2.0	5.0	1.0	6.0	4.0	1.0	5.0	2.0
Max.	5.0	3.0	2.0	6.0	2.0	3.0	8.0	2.0	10.0	9.0	1.0	10.0	12.0	2.0	14.0	4.0

3.3.3 ACGIH TLV for Mono-Task Hand Work

3.3.3.1 Between Facility Comparisons

No risk index is generated by the ACGIH-TLV for mono-task hand work. Risk level scores were not significantly different between facilities when calculated with either the %MVC exertion variable or the Borg exertion variable. The ACGIH TLV hand activity level component score did vary significantly by facility ($p<.01$). Table 32.3 describes the ACGIH TLV scores calculated based on % MVC and peak postures.

3.3.3.2 Within Methodology Comparisons: Effect of Exertion Variable Definition

ACGIH TLV exertion component scores and risk level scores calculated with the %MVC exertion criterion were significantly different than those calculated with the Borg criterion ($p<.01$). Substituting the Borg exertion variable for the %MVC exertion variable elevated scores by an average of 95% in 11 of 14 subjects. Final risk level output derived using the %MVC exertion variable was not comparable to those derived using the Borg exertion variable in 11 of 14 (79%) subjects.

Table 32.3: ACGIH TLV scores calculated with %MVC and Borg exertion variables

	Component scores		Risk level
	% MVC exertion score	Hand Activity Level	
Mean	3.4	2.6	1.1
SD	0.78	1.34	0.27
Min.	2.0	1.0	1.0
Max.	5.3	4.0	2.0

3.3.4 Strain Index

3.3.4.1 Between Facility Comparisons

Strain index risk index scores were significantly different between facilities assessed ($p<.05$). Strain index risk level scores did not differentiate between facilities assessed. Strain index component scores able to differentiate between facilities assessed included the speed of work, duration per day and hand wrist posture by all posture variable definitions ($p<.05$). Our results indicate the strain index methodology was sensitive to differing exposures between facilities assessed and that these differences were reflected in the risk index output. Table 32.4 describes the SI scores calculated with the %MVC exertion variable and peak postures.

3.3.4.2 Within Methodology Comparisons: Effect of Hand/Wrist Posture Variable Definition

Substituting repetition average for peak postures, overall average for peak postures and overall average for repetition average postures resulted in significantly different posture multiplier values and risk index scores ($p<.01$). The effect of substituting repetition average postures for peak postures was an average risk index score reduction of 35% in 11 of 14 subjects. The effect of substituting overall average postures for peak postures was an average risk index score decrease of 55% across all subjects. Lastly the effect of substituting overall average postures for repetition average postures was an average decrease in risk index scores of 39% across all subjects. Our results indicate that calculation of strain index risk index scores based on the 3 posture variable definitions examined resulted in significantly different risk indexes.

3.3.4.3 Within Methodology Comparisons: Effect of Exertion Variable Definition

Substitution of the Borg exertion variable for the %MVC variable resulted in significantly different intensity component scores and risk index scores ($p<.01$). Substituting the Borg exertion variable for the %MVC variable resulted in an increased risk index score by an average of 129% in 8 of 14 subjects and a decreased risk index score by 50% in 1 of 14 subjects. Our results indicate that risk index scores based on the Borg exertion variable definition not comparable to those generated using the %MVC exertion variable in 9 of 14 (64%) of subjects.

Table 32.4: Strain index scores calculated with peak postures and %MVC

	Component scores						Risk output scores	
	Intensity (%MVC)	Duration	Efforts/ min	Posture	Speed	Duration	Index score	Risk level
Mean	5.4	2.9	2.3	2.6	1.3	1.0	139.5	2.9
SD	1.74	0.53	0.89	0.56	0.26	0.23	105.66	0.27
Min.	3.0	1.0	0.5	1.5	1.0	0.8	3.6	2.0
Max.	9.0	3.0	3.0	3.0	1.5	1.5	364.5	3.0

3.3.5 OCRA

3.3.5.1 Between Facility Comparisons

OCRA risk index and risk level scores were not significantly different between facilities assessed. The OCRA additional items factor, duration of repetitive task, and total repetitions component scores were sensitive to inter facility differences ($p<.01$). Our results indicate the risk output of the OCRA assessment was not sensitive to differences in risk of injury between facilities. Table 32.5 describes the OCRA scores calculated with the %MVC exertion variable and peak postures.

3.3.5.2 Within Methodology Comparisons: Effect of Hand/Wrist Posture Variable Definition

Substituting repetition average or overall average for peak postures resulted in significantly different posture multiplier and risk index scores ($p<.01$) but had no effect on risk level. Substituting repetition average posture for peak posture reduced risk index scores by an average of 23% in 12 of 14 subjects. Substituting overall average postures for peak postures reduced risk index scores by an average of 24% in 13 of 14 subjects. Changing posture variable definitions resulted in significantly different risk index scores in 93% of subjects.

3.3.5.3 Within Methodology Comparisons: Effect of Exertion Variable Definition

Substituting the Borg exertion variable for the %MVC variable resulted in significantly different component scores ($p<.01$), risk index scores ($p<.0001$) and risk levels ($p<.001$). Substitution of the Borg exertion variable for the %MVC exertion variable increased risk index scores by an average of 88% in 11 of 14 subjects and reduced risk index scores by an average of 64% in 2 of 14 subjects. Substituting the Borg exertion variable for the %MVC variable resulted in significantly different OCRA risk index scores in 13 of 14 (93%) of subjects.

Table 32.5: OCRA index calculated with peak postures and %MVC

	Component scores							Risk output scores	
	Intensity (%MVC)	Wrist posture	Additional factors total	Hours recovery	Mins/ day	Total reps/ day	Rec. actions	OCRA Index	Risk level
Mean	0.4	0.6	0.9	0.7	349.4	6218.8	1170.9	12.1	2.4
SD	0.18	0.06	0.06	0.43	138.40	4440.06	1043.97	17.21	0.63
Min.	0.01	0.5	0.8	0	162.0	208.0	0	0	1.0
Max.	0.8	0.7	0.95	1.0	617.0	13965.0	3109.7	51.9	3.0

4 Discussion

4.1 Sensitivity of Risk Assessment Methods to Facility and Worker Assessed

Mean risk level assigned by all the methods examined, with the exception of the ACGIH TLV calculated with %MVC, indicates that there is risk of musculoskeletal injury associated with performance of the board edger job. While a finding of job risk based on the risk level score is sufficient to determine if a job common to an industry is “at risk” it is insufficient to identify site specific problem exposures and direct site specific interventions. The two facilities examined in this study report meaningfully different incidence rates (facility A- 0.22, facility B- 1.33) yet no differences were observed in risk level scores in any methodology examined. It stands to reason that if differences in the physical exposures between the facilities are in part responsible for the greater then 6 fold increase in incidence, the problem exposure(s) should be detected by the risk assessment methodologies. Part 1 of this series (JONES & KUMAR 2006) identified significant differences between facilities assessed in all frequency variables examined. Additionally, the total exposure of workers in facility B was significantly higher then facility A.

The calculation of the risk methodologies using quantified physical demands data has demonstrated the sensitivity of the risk index scores of the methods to individual worker technique. Sensitivity to worker technique confirms that a number of worker assessments are required to derive a representative risk index score for the facility. Should representative risk index score for a job specific to a facility be derived it may be possible to differentiate between facilities known to have meaningfully different incidence rates (such as the case with the two facilities examined in this study). Significant differences between facilities were observed in component scores, combined scores and risk index scores in all methodologies indicating that at least some aspect of the methodologies were sensitive to differences between facilities. Only through interpretation of the component and risk index scores does the work site evaluator gain insight into the problem exposures. The ACGIH TLV, SI and OCRA procedures detected significant differences between the facilities in frequency and duration component scores. Only in the cases of the SI and REBA assessments did these exposures result in integrated risk output (risk index scores) which differentiated between facilities. This finding is important as it suggests model of MSI injury causation upon which the assessment derives a risk output may be accurately describing the relative role of the variables in MSI causation. If the relative role of the exertion variables has been assigned industrial prevention efforts which use the methods to direct intervention stand a greater chance of success.

4.2 Effect of Posture and Exertion Variable Definition on Risk Output

In each of the methodologies examined the posture or force variable definition used has been shown to result in significantly different component, combined component and/or risk output scores. Posture variable definition, thereby its calculation, resulted in significantly different scores in every risk assessment methodology considering posture, influencing risk index scores by as much as 55%. Exertion variable definition resulted in significant different risk assessment scores in all methods in which either definition may be applied, affecting scores in both directions (may reduce or increase scores) by as much as 129%. The primary literature describing the ACGIH TLV, SI, and OCRA methods suggests either the %MVC required to perform the job or a Borg rating of exertion may be used to define the exertion variable (MOORE & GARG 1995; COLOMBINI 1998;

UNIVERSITY OF MICHIGAN 2005). Our results indicate the Borg exertion variable and the %MVC exertion variable, as they have been defined in this study, are not equivalent.

Further studies exploring the affect of posture and exertion variable are needed to provide insight as to the best variable definition to be used. In order to examine the predictive validity of risk methodology component and risk index scores a greater amount of detail is required from occupational health surveillance systems. Studies seeking to identify problem exposures in at risk jobs must be based on representative quantified physical exposures and draw on a standardized surveillance system which accurately records the industry, occupation, severity of injury, and exposure to the job. While this study has recorded quantified demands in a representative sample (88% of population) neither the occupational health records of the facilities examined nor Workers Compensation Board dataset provides sufficient information to examine the association between risk assessment scores and incidence of injury. With respect to the site specific surveillance systems the unique nature of the systems limits our ability to draw meaningful conclusions based on the grouped data. In the case of the Workers Compensation Board dataset no information is collected on the total number of workers performing the board edger job. Additionally, the resolution of the "occupation performed" data fields is insufficient to enable specific production jobs to be identified. Given these limitations, our ability to delve further into the relationship between the exposures and the incidence of injury is limited to the suggestive analysis performed. In this case it seems total exposure to the job has resulted in a higher incidence of musculoskeletal injury in facility B and that the integrative models of MSI causation used by the SI and REBA assessments were best able to identify this difference.

5 Conclusion

In light of the foregoing data and discussion of the risk assessment methods the following general picture can be drawn: All the methodologies examined (with the exception of the ACGIH TLV) have identified a level of risk in the repetitive board edger job. Risk assessment methodologies which consider multiple body regions, broad exposure groupings, and output ordinal risk index scores were less sensitive to differences in worker technique than methods requiring increased resolution to assign component scores and use multiplicative model structure. All methodologies examined were significantly impacted by the posture and exertion variables chosen. Future studies examining the association of risk methodology model output and incidence of MSI are needed which draw on representative quantified physical demands and detailed incidence information to improve our understanding of how integrated physical exposures result in MSI. To this end it may be desirable to develop risk indices and their predictors with greater specificity and sensitivity. An interpretation of multiple body regions in a single task with varying risk of injury obscures the risk assessment picture. Evidence based risk indices with rigorous epidemiological validation is essential to increase the level of scientific sophistication. As our understanding of MSI causation improves the utility of ergonomic risk assessments to direct effective prevention will improve.

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33 Work Science and Aviation Safety

Heinz Bartsch

1 Introduction

It has become increasingly clear in practice that the requirements placed on pilots and their crews are becoming increasingly complex and difficult. Not least of all, questions of aviation safety also have to be addressed in this respect (Safety – “The state of not being threatened, which is objectively presented by the presence of protection or the absence of sources of danger, and that is perceived as the certainty of individual and social structures regarding the reliability of protective devices.”/Meyers Lexikon 1980/. Despite DIN 31619-2 and DIN 32541, however, it must be assumed that there is no generally valid definition of the expression “Safety” at the present time. The formulation “State of being protected” (Neues Deutsches Wörterbuch) or the relation to the expression “Risk” also fail to improve this situation. One can, however, assume that there is no “absolute safety”. On the basis of DIN 31000, one could support the position that “Safety” could be understood as the “situation in which the expectation of damage in the socio-technical system is acceptable according to any reasonable standard of measurement”.).

The problem of “aviation safety” is characterized by an extraordinarily high level of complexity.

An important causality thereby arises from the effects of the Man – Technology – Organization interaction at many levels.

International comparable investigations of aviation accidents make it clear that the relationship has shifted strongly from the technically-related complex causes that were originally considered to human-related causes.

Nowadays, it must be assumed that almost 75% of all aircraft accidents are caused by “human error”. It is therefore clear that, in the sense of their “reliability”, all human beings must be regarded as the weakest link in the above-mentioned chain of interactions.

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Work Science/Ergonomics deals with the conformity of human work with natural laws and the conditions for its effectiveness in a very interdisciplinary way.

On the basis of the knowledge gained from this, it is above all working systems– thereby also including "flight working systems" – that should be optimized from the viewpoint of the central importance of human beings.

A central category here will thereby be "Human Reliability".

In doing this, ergonomics attempts to achieve two major objectives by employing a systematic approach:

- Increasing the performance of the system,
- Increasing the reliability of the system.

"System reliability" thereby includes the partial reliabilities of the technology, the organization and, above all, people as an interconnection with an integral effect.

In the following contribution, the author thereby proceeds from the hypothesis that a considerable improvement in aviation safety can be expected from a targeted optimization of the "human reliability" and its corresponding integration into the overall reliability of the system.

Work Science / Ergonomics can thereby make a significant contribution here.

2 Accidents in Air Travel

Without making any claim to completeness, a summary of statistical surveys of accidents occurring in air travel (HANKE 2003) indicates the following events:

- 630 passenger aircrafts were destroyed worldwide in operational use between 1958 and 2001,
- The sudden and serious increase in the "Total Losses" curve are striking (total losses of scheduled aircraft),
- The increase in accident figures are always registered after the introduction of a new aircraft generation, or in other words, after significant technical changes to the aircraft (incl. the cockpit),
- The 1st cockpit layout generation was introduced in 1960 (e.g. B707, DC8, Caravelle),
- The 2nd cockpit layout generation followed in 1965 (e.g. B727, DC9, F28),
- The introduction of the "early wide-bodies" took place in 1971 (e.g. B747-200, DC10, A300),
- Airbus placed the A310 into regular service in 1983. The era of the "glass cockpits" began with this aircraft, i.e. a modified manner of processing the information from the cockpit instruments – mainly electronically using computers/display in modified instruments of the older generation or simple small display screens,
- The 3rd cockpit layout generation, with screen technology for almost all systems, was introduced in 1986 (e.g. B747-400, MD11, A310),
- In 1988, Airbus revolutionized the market with the A320.

- On a large scale, scheduled aircraft are equipped with “Sidesticks”, i.e., with a modified type of aircraft control/vector control,
- Airbus forecast the development that the number of accidents would increase strongly up to the year 2017, particularly for the 3rd generation,
- A number of A380s have been delivered to various international airlines in the meantime,
- The most extensive on-board control systems for scheduled aircraft in civil air traffic are also being increasingly discussed and investigated. Solutions of this kind have already existed for some years in military air traffic (drone systems) and in the deployment of helicopters.

If the flight accidents are registered in a differentiated manner, the following overview results:

Table 33.1: Differentiated accident incidents in civil air traffic (based on FABER 1994)

Distribution by cause			**Risk by flight phase**		
1.	**Crew:**	**75 %**	**1.**	**Landing approach:**	**25 %**
2.	**Aircraft / Technology:**	**9 %**	**2.**	**Landing:**	**24 %**
3.	**Weather:**	**7 %**	**3.**	**Take off:**	**24 %**
4.	**Flight control:**	**5 %**	**4.**	**Cruise level approach:**	**12 %**
5.	**Maintenance:**	**2 %**	**5.**	**Climbing:**	**6 %**
6.	**Miscellaneous:**	**2 %**	**6.**	**Rolling:**	**5 %**

Distribution by H - accidents (from 1963 – 1992)

Development:

H 1 = 40 %	**H 1 = 52 %**	**H 1 = 27 %**	**H 1 = conscious, deliberate work error,**
H 2 = 49 %	**H 2 = 34 %**	**H 2 = 19 %**	**H 2 = unconsious, unintentional error,**
H 3 = 11 %	**H 3 = 13 %**	**H 3 = 54 %**	**H 3 = training (qualification deficits),**
H 4 = 0 %	**H 4 = 1 %**	**H 4 = 0 %**	**H 4 = error due to nausea/ sickness.**

In this connection, the FHP e.V. (Forschungs- und Arbeitszentrum Hochschulausbildung von Piloten e. V. – Research and Higher Education Working Centre for Pilots) determined that H 3 accidents have more than *quadrupled* in the time period from 1963 to 1992.

It goes without saying that these analyses could also continue with an international differentiation. This is not the main objective of this contribution, however. Statistically secured comparisons to other modes of transport clearly indicate *that the aircraft can still be regarded as the safest means of transport*.

Every aircraft accident is one too many, however.

If you only consider the increase in the density of air traffic that is expected for the future (for European air space, it is assumed that the density of air traffic will triple by the year 2020), the increasingly cut-throat competition between the many airlines, the “masses” of people and goods to be transported (e.g. A-380) and the need for mobility due to economic development, above all in Asia (China, India, Vietnam), the extent of the damage that could arise for people and goods will become clear.

It is therefore all the more important to investigate the causes that mainly appear to be responsible for this kind of development. In the following contribution, within the sense of the Man – Technology – Organization interaction chain, the author has thereby concentrated on the "Human reliability" factor in flight work systems, their possible determination and specific ways of influencing them.

In recent times, and in particular in Germany, Switzerland and Austria, there have been "movements" in regard to these questions, which encourage hope for fundamental solutions.

In doing this, it is clear that we must not forget Work Science/Ergonomics.

3 Findings Regarding the Training of Transport Pilots

In recent years, the work of the transport pilots in civil air traffic has experienced serious changes, for example, as a result of new technologies and increased automation, above all in the cockpit.

The increasing complexity of the overall air traffic system, the extended and qualitatively changed range of tasks in the cockpit, the growing density of air traffic, the enormous increase in competition for all airlines and an exponential increase of H 3 accidents (see Table 33.1) call for a critical examination of the ATPL (Airline Transport Pilot Licence) training of all pilots that has been carried out up to now.

The increasing problems that arise from the considerable increase in the demands on pilots in the increasingly complex Man – Machine – System must be solved, above all, by a high level of training.

According to earlier analyses, there are neither scientifically-based works analyses and qualification profiles for transport pilots, nor a state-recognized professional qualification (FABER 1994). If a pilot loses his flight authorization, for example for health reasons, he can certainly fall into a deep "social abyss".

For this reason also, a university education for transport pilots should be required, which should be completed with a double qualification (graduation or Master's degree + ATPL). Against the background of the implementation of the JAR-FCL (European Directive for Crew Licensing (replaces LuftPersV)) (new European regulations), no further time delays should be permitted here.

If it has to be determined that aircraft technology has developed significantly faster than the training of pilots, there are indeed clear signals of this.

A new and comprehensive curriculum and its implementation must therefore be promoted here, and not another one-sided orientation on (multi-choice) examination questions.

It is generally accepted that, with higher levels of automation and thereby the higher complexity of the transport aircraft of the 3rd jet generation, pilots with higher qualifications will also be required.

As a result of the changes in air traffic described above and through the concrete development of new commercial aircraft, the working conditions for the pilots and their crews have changed radically with respect to quality. The key features are listed below:

- The "cockpit" workplace has changed considerably through automation,
- The cockpit team has shrunk from the former 5 to only 2 members,
- Motorized standard activities of the pilots are on the decrease,
- Monitoring work and system management dominate in normal operation (high cognitive requirements and influencing of the vigilance status),
- Highly automated digital fly–by– wire glass cockpits are very convenient in normal operation,
- In the case of a fault, the high level of complexity leads to a greater density of information, which can endanger the control of the system by the pilots,
- Human factor accidents of category H 3, which arise from training and qualification deficits, have increased exponentially since the 3rd jet generation.

According to Faber, the following "Qualification shifts" for the pilots will be noted above all for the 3rd jet generation of commercial aircraft: Pure operational activities – and manual flying in particular (important for certain fault situations) – will be increasingly carried out in the background.

After an extensive flight preparation in the ground, "monitoring" will be the main task of the pilots in normal operation. Apart from the stricter vigilance problems, the new systems of the 3rd jet generation of commercial aircraft are mostly very convenient to operate.

High information densities, strong cognitive demands and thereby a heavy loading of the pilots only clearly arise in fault situations. Above all, this thereby results in a situation that is very different from the 1st generation.

Previous basic skills that are no longer related to the procedure lose their significance in normal operation, while extra-functional, longer lasting and comprehensive, so-called "key qualifications" are increasingly necessary and will have to be correspondingly defined.

These increasingly convenient, user-friendly systems with a high level of automation can certainly also be flown by pilots with lower qualifications in the normal case. So-called "Push-button operators" can thereby certainly be successful in normal operation when working on very complex hybrid systems.

Things are, however, completely different in the case of possible fault or accident situations.

A higher level of qualification will always be required here for a successful and safe manual takeover, so that the possible defective system can still be controlled.

Aircraft manufacturers and even airline operators have occasionally claimed that aircraft of this type can also be safely flown by less qualified pilots. If this claim seems a little dubious for the normal operation at least, it is definitively always wrong for fault situations. Under this aspect, one should also take into account the satisfaction of the large demand for pilots arising from airlines in the Asian area, and thereby on the possible endangerment of international aviation safety.

In particular, accidents in recent years have shown that the insight of the pilot into the higher system levels alone is not sufficient, and that, above all, information and/or know-how regarding the system relationships must also be guaranteed. If the pilots have deficits in this area – and this can generally be assumed – this could lead to fatal consequences in cases of faults.

At the same time, however, a warning must also be given here regarding systems that have a complexity that is sometimes unnecessary, and thereby too high. Systems of this kind can thereby often no longer be controlled, despite a comprehensive and high quality pilot training. A core question regarding the principle of the functional division between Man and Technology is thereby raised.

The difference between a trained operator and a qualified pilot with the corresponding capabilities become particularly clear in the case of faults in the system.

The qualified operator (pilot) who is just sufficient for the normal operation fails in the case of a fault, in which manual takeover, fault analysis and thereby a decision and measures to avert danger are necessary – frequently under extreme time pressure.

In contrast to the 1st generation, the following have above all become necessary for the control and operation of the 3rd generation:

- Programming,
- Monitoring,
- Fault prevention,
- Fault analyses,
- Any trouble shooting,
- And finally manual takeover (getting into the loop).

The above remarks certainly make it clear *that the training of the pilots must be carried out according to the basic principle of having the best-possible qualification of pilots and crews available for the worst possible situation (fault).*

In this prospective sense, it can be justifiably assumed – as is also possible in other areas of working life –that the sources of danger will be identified and eliminated, so that damage cannot arise at all. Although the fixed costs in the sense of a prospective work planning (e.g. a university education) may be somewhat higher, the variable costs can, however, be reduced enormously in the medium to long term through the minimisation of risks and damage.

4 Human Reliability in Work Systems

As a synonym for the expressions "Man – Machine – System" or "Socio – technical system", the expression "Work system" can also be used, which has generally become increasingly established in the Work Science literature.

The advantage of the system approach is that it permits a generally valid method of presentation for the structure of very different phenomena.

The performance and reliability of a work system from the viewpoint of Work Science/Ergonomic objectives can be established above all through the use of findings from the *Stress – Demands concept* (deployment of the person) and from the viewpoint of the transformation of information with the help of ergonomic system considerations.

The following illustration shows this connection:

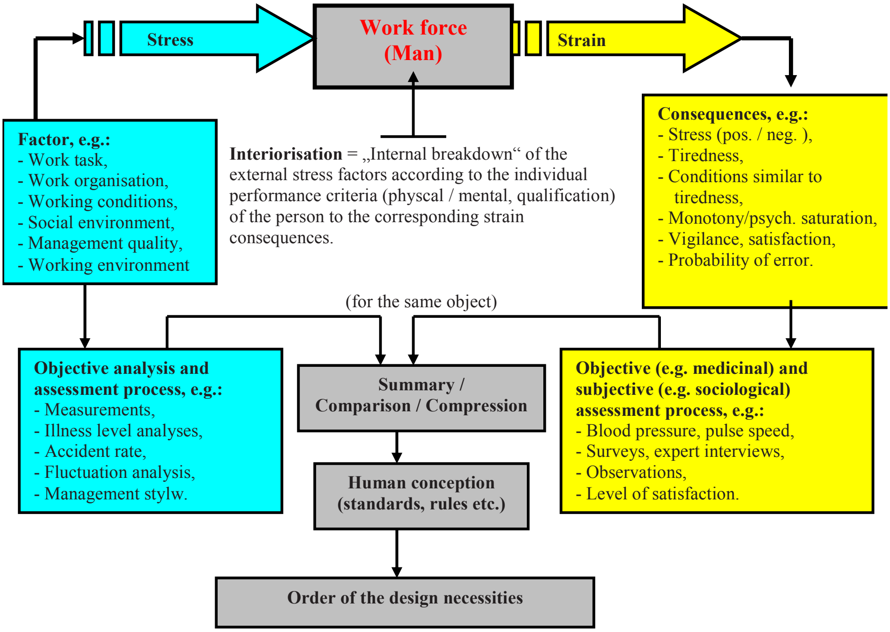

Fig. 33.1: Stress – Strain concept **(**BARTSCH 2004a,b**)**

In the author’s opinion, there are a number of direct connections between these considerations of the Stress – Strain concept and human reliability.

BUBB (1992) defined human reliability as follows:

“Human reliability is the capability of the person to carry out a task under pre-defined conditions for a given time period within the range of acceptance.”/3/

Using the same basic approach, BARTSCH (2004a,b) extended this definition by naming the important boundary conditions, and formulated it as follows:

“The ability of the person in the work system to bring a suitable qualification and the corresponding physical and mental performance preconditions into a specific work process, and to become effective. This should contribute towards a predefined task being carried out under specific conditions and in a predefined time period, whereby technical, economic, humanitarian and ecological criteria and a failure acceptance range are respected.” (BARTSCH 2004a,b).

Fig. 33.2 shows the major factors that influence human reliability:

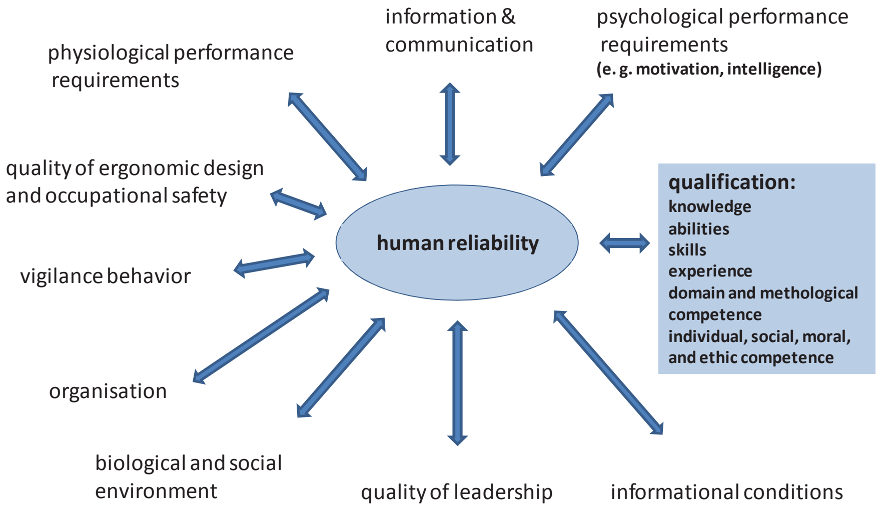

Fig. 33.2: Factors influencing human reliability **(**BARTSCH 2004a,b**)**

In contrast to Bubb, who saw a linear dependence between human probability for error and human reliability, the author regards human reliability as a structure that is far too complicated to allow itself to be adequately determined simply by a mathematical relationship of this kind.

The value of a statement assigned in this way is, in the opinion of the author, also controversial from the viewpoint of the other levels:

(1) In this case, it is quite clear that “Error” has been equated and/or confused with the actual “Cause”. Between the actual “causes” of a possibly different human reliability (assignment, execution or working conditions, human disposition factors, etc.) and the “errors” or the “error probability”, however, there are the “Interiorization process” that are so important for the respective individual human reliability (see also Fig. 33.1).Through this interiorization process, the author see a greater “proximity” to human reliability than to the probability of human error . Human error, or the probability of human error, are to be understood in the scientific sense (e.g. Black–Box method) as a “Result” or “Output” of the upstream processes. *You therefore come closer to human reliability if you consider the dominant characteristics of this interiorization process. There are, however, no linear, mathematical relationships to be expected here.*

(2) Up to today, one cannot assume that there is a uniform and convincing opinion in the specialist literature regarding the possibilities of the classification of human error.

There could be occurrence- and achievement-orientated, cause-orientated, or combined methods.

Human error can have a stochastic or deterministic character. Furthermore, a classification can only be carried out if human error occurs randomly, sporadically or systematically. What will then be the relation to the above-mentioned “aAcceptance range” if we assume that there is a “human right to make errors”?

That human reliability can be understood in this context as a characteristic/feature, as well as a performance characteristic/feature at the same time, is shown in a simplified manner in Fig. 33.3:

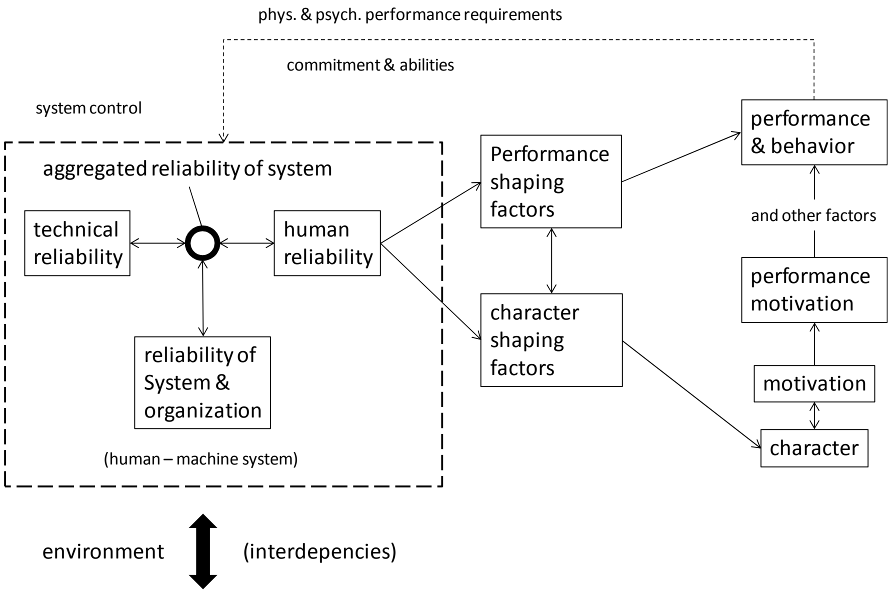

Fig. 33.3: Human reliability as a performance and character feature **(**BARTSCH 2004a,b**)**

The author assumes that at least the correlations shown in Fig. 33.2 must be verified by systematic investigations. Extensive results are already available in some areas in the form of dissertations, habilitation dissertations and other scientific works using the example of different target groups (e.g. pilots, surgeons, managers). This work should be continued, and could be used to obtain a corresponding overall picture of the determination of human reliability in the work process.

5 Behaviour in the Flight Work System

The preceding items and explanations will be used in the following as an example relating to the problem of aviation safety.

In doing this, it is assumed that the fulfilment of tasks in flight work systems depends in particular on the manner in which the tasks are handled. The question of *the behaviour of the work system that can be expected* arises in this context, among other things.

Characteristic system features for this are (DORN & BARTSCH 2004):

- The work system exists in reality and is relatively open to its environment. It presents itself as a natural entity, and follows the scientifically known natural descriptions within its areas of validity,
- The work system forms a network of interactions with and within its elements and its environment,
- A main element of the work system is the operating material: it is a technical product that is largely characterised by linearity (EILENBERGER 1990). It works in a functional manner, and the behaviour can be generally described and predicted through causal chains,
- A further main element of the work system is the human being: A natural object that is characterized by non-linearity. Although the human being works in a “goal-oriented” manner, his behaviour can, however, only be partly described by means of through high-dimensional, complex causal fabric (EILENBERGER 1990, p. 80). An essential orientation aid for the description of the behaviour of the human being is, among others, also the “conception of man”.

According to GEROK (1990), the preconditions thereby exist for the situation in which a system can no longer be fully predicted, despite knowledge of the initial conditions. *Processes that run in accordance with the conditions described above can thereby no longer be mathematically described with the help of a linear differential equation.*

For the problem that we are considering, it can thereby be assumed that “Order” and “Chaos” represent the corresponding behavioural elements of this work system.

The practical results of investigations from air travel partly confirm this conclusion.

For further processing of the problem, it can therefore be assumed that the flight crew can be considered to be a “collective construction” of the corresponding employees of the commercial aircraft under consideration.

It can thereby also be assumed that, among other things, the complex, natural behaviour of the flight crew will pursue the goal of ensuring the corresponding protection of the work system (According to DIN 31004, Part 1, “Protection” is understood to be the reduction of the risk through suitable precautions, that reduce either the frequency of occurrence or the extent of the damage, or both. Risk is described through the frequency (probability of occurrence) and through the extent of the damage to be expected (significance)).

No protection of the work system against threats can take place, however, if the aircraft crew finds itself in a state in which it is no longer capable of regulating its own relationship with the environment or of self-regulation.

According to this principle, a theoretical-hypothetical approach can be developed that takes the following positions into account:

- A certain level of internal self-organization and/or the regulatory behaviour feedback of the flight crew on the basis of limited resources,
- The flow ("Interiorization flow"/see Fig. 33.1) of collective interiorization parameters as a measure of the common Stress-Strain level of the crew in this case. It forms the "cause" of the regulatory activity of the flight crew,
- The level of apportioned *agility*, i.e., the "flexibility" of the flight crew in bringing a different level of regulatory activity into the system and allowing it to take effect (see: Definition of the expression "Human reliability" by Bartsch).

A "flight crew subsystem" feedback of this kind is shown in a very simplified way in Fig. 33.4.

Initially, only those elements have been picked out from Fig. 33.4 that could be particularly relevant for the determination of a possible mathematical model.

The job holders receive the corresponding information from the respective *air operation status* (*Flugbetriebszustand)*.

The resulting perceptions are then processed in a cognitive process through the safety-orientated comparison of the objective operational risk with a corresponding subjective operational imaging system (OAS). Possible perceptual distortions remain initially unconsidered.

The result of this leads to a subjective assessment of the effective objective risk potential (HACKER 1998). The subjective attitude of the human being to the risk (in relation to the characteristics of his awareness of danger and safety) is an important *activation parameter* for protective measures, in which the findings from the risk compensation theory must be taken into account (BUBB 1992).

Decisions, selections and activation of actions that become genuinely effective for the protection from dangers are understood as "protective measures". The corresponding protective measures will be agreed with the crew. The agreement on action on this (Multi Crew Coordination und Crew Resource Management) thereby represents an essential element of the internal self-organization of the work system.

The time that is necessary for this is integrated into the system behaviour as the corresponding reaction time of the flight crew.

The work requirements that arise from the operational phases of the work system (Phases of Flight – POF, see ATA iSpec 2200), the respective work content and the associated miscellaneous working conditions lead to the corresponding *work stresses.*

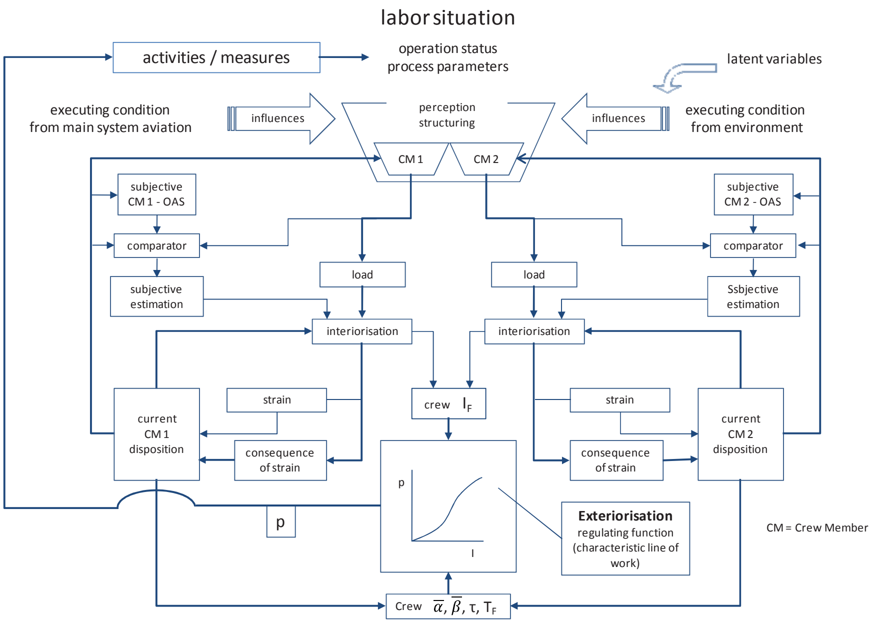

Fig. 33.4: Hypothetic "flight crew subsystem" with feedback **(**DORN & BARTSCH 2004**)**

These work stresses – together with the subjective assessment of the objective risk as a possible special mental stress component – then lead through the *individual interiorization process* to a corresponding *stress level* with given *consequences*.

The author hereby assumes that the change in the "interiorization flow" represents the root cause of the "regulatory activity" of the flight crew (for example, to ward off threats). Many and very complex correlations thereby exist between the characteristics of the human reliability (see Fig. 33.2) and the inner performance disposition of the person/persons.

On the general basis of the above description, there is now the possibility, in line with BLOME et al. (2004), of describing the behaviour that was described above and the stability of flight work systems in the form of a mathematical model using non-linear differential equations.

The treatment of this mathematical model step-by-step is not completely possible here for reasons of space.

The factors of tiredness (vigilance) and regeneration are not initially taken in to account in this model, however.

The main expressions are "set" with:

- Regulation activity P_F
- Carrier capacity T_F
- Relative regulation activity p
- Interiorization flow I_F
- Agility of the aircraft crew A_F

- Level of the relative regulation activity at Work Point P_0
- Marking the output position of the system status consideration Index 0
- Control parameter α

The behaviour of the sub-system, starting from the initial status p_0 (work point), can thereby be considered through the increase or decrease of the interiorization flow.

For the determination of statements regarding the *stability behaviour* of systems with feedback, the reaction times of the crews (which arise through the intake and processing of information and the cognitive processes and internal agreements on action that arise from these) must also be taken into account.

6 Conclusion

With this contribution, the author wishes to draw attention to the fact that there is clearly a close relationship between human reliability und effective, safe and humane flight work systems, above all from the viewpoint of aviation safety.

Despite, or perhaps because of the increasing cockpit automation, the rapid increase in air traffic density, the increased competition between the airlines and other safety-relevant factors in aviation traffic, it is above all the human being, with his capabilities, but also with his weaknesses and performance limitations, that is subject to a particularly critical consideration in this contribution.

The increasing number of aircraft accidents that are caused by human factors give alarming signals in this respect.

It is therefore necessary to rigorously face up to this problem, both scientifically and in practice, and to relatively quickly find solutions here that will completely and comprehensively identify this continually increasing risk factor and that can react to it with suitable measures.

An initial possibility for this is outlined in this contribution, which requires further intensive research work, however.

The part that could be played here by Work Science/Ergonomics, among others, has also been indicated in this contribution.

If our purpose here is above all to improve the air traffic management, and thereby also aviation safety, through a prospective work design so that users and customers will achieve a higher level of satisfaction, we should also consider this complexity in the context of scientific research in the future, and learn to think and work in a genuinely interdisciplinary manner, and thereby make a valuable contribution to the better qualification of the personnel who determine and accompany flights.

This contribution will have served its purpose if it has been able to stimulate further reflection on the subject.

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34 Development of Theory and Practice in Ergonomics

Vladimir M. Munipov

The author had long been thinking about writing this article. In the USSR, and subsequently in the post-Soviet period, one of the factors limiting the development of ergonomics was a misunderstanding of its core by overwhelming majority of engineers, designers, developers and technologists. In those cases where they had begun to realize its importance and then learned this discipline, previously unknown to them, I encountered a resistance to incorporating its principles and data in engineering and design activities. This was substantiated by the fact that ergonomic statements had often been formulated only in a qualitative form, and not in a quantitative one. The view of the specialists at the time can be expressed by the following quote: "Give us mathematical formulas of properties and activities of human beings and then we'll use them fully in our calculations and projects". They were deaf to objections that, in this case, it would be somewhat robotic. In other cases, without reason and in a harsh manner, they said: "Do not get involved in our business. In that case we'll finish all the engineering development, then you can deal with convenience, comfort, health as well as design beauty." It is noteworthy that two engineers, who studied at prestigious technical universities in the Soviet Union, found themselves in industrial design and became leading specialists in the All-Union Scientific and Research Institute of Industrial Design (VNIITE). The staff of the institute carefully watched over their activities, seeking to understand the origin of this phenomenon and thus establish a more reasonable relationship with those specialists in their field. Moreover, the director of VNIITE Y.B. Soloviev was literally forcing ergonomists still at the initial stages to participate in project activities of industrial design. At the same time, he urged all the staff that a compulsory close cooperation with the designers, engineers, technologists and economists, should be an immutable rule of such activities. Therefore, the discovery of new forms of business interaction with the above-mentioned professionals in an immediate sense had become a matter of the ergonomists's survival at the institute. They studied design activities. The author used the study and adoption of foreign experience. Here for the first time he was attracted by figure of H. Luczak, mainly because his aspiration to ergonomics was something

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like the adoption of industrial design by those two engineers of VNIITE. He had studied machine-building-oriented engineering in city of Darmstadt, after which he began to study the influence of information stress and mental loading on human beings. That study was presented in the content of a dissertation, which he successfully defended and received a positive response from the known ergonomist W. Rohmert. In a sense it seemed that H. Luczak had not chosen ergonomics, rather it had chosen him. I think the latter is closer to the truth. Moreover, my institute's ergonomists reached the same conclusion, examining the two aforementioned engineers in VNIITE. It seems to me in this regard H. Luczak and I absolutely matched. I can make judgments about myself based on the feedback from my colleagues. Of course, it had been affected by the differing standards of Soviet engineering training, compared with standards of German high engineering education of H. Luczak. In a professional sense we moved from two critical elements of ergonomics – from engineering (H. Luczak) and from psychology (V. Munipov 1979). Therefore, the study of Luczak's works on the theory and practice of ergonomics enriched me by a deeper understanding of the role and position of engineering within ergonomics, which in turn allowed us to develop a procedure for the joint work of ergonomists and engineers at the institute in shorter time and at a high level. An important point for the author himself was to raise awareness of and answer the question: How two ergonomists developing ergonomics in the two polar socio-economic conditions – in a socially oriented market economy (H. Luczak) and in the planned economy with its command-administrative management system (V. Munipov) – came to the same goal: human-centered design and then from its positions clearly evaluated all phenomena in ergonomics and especially the fact of ignoring the human-oriented direction? This is not a simple matter taking into account that the planned economy did not need ergonomics and design. It is time to tell why author hadn't write this article before now.

There is no need to describe the socialist economy in this article. However, some details of the lives of people in the USSR should be recalled so that there is a clear understanding of the difficulties that the author was confronted with while writing. During period of the 1930s to the 1950s industrial products were withdrawn from the sphere of culture at that time. Those products were treated merely as tools to build socialism. However, to tell the truth, the image of the USSR during this period was one of indigence. This was a habitual lifestyle for millions of people who never could have imagined anything different. The Iron Curtain was impervious. The official "modest but optimistic" lifestyle and sanctioned taste received the new and more crucial impact after the end of World War II. The achievements of space exploration – Sputnik in 1957 and Major Yuri Gagarin's mission in 1961 seemed to indicate that Soviet technology was advanced enough to provide ordinary people with better quality housing and consumer products. However, millions still lived in communal apartments (*communalka*) which were partitioned rooms with one kitchen and one bathroom for several (two to fifteen) families. As the population grew, more partitions were put up.

As time passed, the situation became more dangerous for the ruling party. In October of 1961, the XXII Communist Party Congress approved the new party program and decided to pay more attention to industry, which included manufacture of consumer products. Khruschev's reforms began to have an impact on people who understood that improvements were not possible without design and ergonomics.

VNIITE was set up in 1962 as the country's first ergonomics department led by Munipov M.V, Dr.sc., and Zinchenko V.P., Dr.sc. The department was the mightiest unit in this field in the country. With the revival of Soviet ergonomics in the 1960s, it inherited some social enthusiasm of the 1920s, which manifested itself in trying to overcome the existing stereotypes, in the search for the novel, and in the striving for unceasing inventions (N N 1983b). In the 1960s ergonomics was regarded by many as a sign of changes in the studies on labor, with the resulting basic improvements in equipment, processes and conditions of work. At the same time, it was just because of this that bureaucrats and some senior managers of ministries and departments were at great pains to impede its progress. I would like to mention that in 1970s the author was accused of advocating a bourgeois pseudo-science, that is, ergonomics. The accusations followed a set-up used in the late 1940s to declare cybernetics a pseudo-science.

To be through with the author once and for all, certain senior managers of the State Labour Committee and the All-Union Central Council of Trade Unions tried to give an ideological tinge to accusations through alleging that by promoting ergonomics the author undermined Lenin's principles of scientific organisation of labour and labour protection. Accordingly, they insisted that the author be kept away from all work related to the development of ergonomics in this country.)

Missions of VNIITE's Ergonomics Department were:

(1) Fundamental ergonomics research (N N 1970–1986).
(2) State ergonomics standards and ergonomics requirements for general technical standards development (N N 1967, MUNIPOV et al. 1982).
(3) Design of the most complicated user interfaces for showing ergonomics capability.
(4) Ergonomics criteria elaboration for products quality evaluation (MUNIPOV et al. 1982).
(5) Ergonomics education reform preparation (MUNIPOV & ZINCHENKO 2001, ZINCHENKO & MUNIPOV 1989).

Most ergonomists of VNIITE participated in the project works of industrial design. In 1973, one of the more meaningful of VNIITE's works was presented to the Italian Utita Company. It was an advanced lathe and it considered a triumph of industrial design and ergonomics. The significance of this project was the attraction of maximum attention to the person through the equipment design. At that time designers and ergonomics experts worked together as an effective team (MUNIPOV 1978). This machine serves as a convincing evidence that when VNIITE had gotten enterprises' orders from countries with a market economy, it was accompanied by professional success. At the same time, it became clear that industrial design and ergonomics within a “planned economy” were not needed. Furthermore, it was rather dangerous for the system because it demanded social changes in the cultural and economic spheres, and it could bring changes in the officially approved mentality. Now when many years have passed I can understand that those, who had upheld the official ideology, quite rightly criticized ergonomists, who, the former believed, had permitted a great deal. Designers and ergonomists were a power that represented an opposition to Soviet system because their values and philosophy were humanistic.

Ergonomics in the VNIITE had an obvious Western face, nature and genesis. Thus, ergonomists were smart enough not to tell communist authorities that ergonomics was a good thing. Instead, they promoted its utility and usefulness. Hence, the main emphasis of VNIITE’s activity was shifted toward ergonomics of industrial equipment. Ergonomics activists, including my colleagues, and myself tried to convince the authorities that ergonomics would increase productivity. VNIITE’s director Y. Soloviev was a talented young designer. He brought to VNIITE a flexible balance of functionality and beauty; a sparking sense of humor, and a feeling of hard responsibility. This spirit strengthenedVNIITE through the decades. We felt the spiritual unity of the design and ergonomics community. Thus, VNIITE was an unique agency in this aspect. In 1975 Y. B. Soloviev was elected as ICSID President.

The international activity was one of the most intriguing of VNIITE’s enigmas. Y. Soloviev along with the deputy chief of the USSR State Committee of Science and Technology GVISHIANI (1972) were creating VNIITE’s image as the most open Soviet institution behind the Iron Curtain. One of the most effective forms of international exchange was the scheduling of design and ergonomics exhibitions from countries with the best design and ergonomics achievements. Each show was accompanied by a professional seminar, but the most valuable feature was the opportunity for informal contacts with Western ergonomists and designers. In 1972, the 1st International Conference of Ergonomics from CMEA countries met in Moscow. IEA’ President B. Metz took part in it. In 1974, these countries signed an agreement on scientific and technological cooperation in this field (MUNIPOV 1981).

Thus, VNIITE’s ergonomists, systematically learning by foreign experience concerning ergonomics and industrial design (MUNIPOV 1982), at the same time used any opportunity to develop their disciplines in the planned economy. Just today, I realized that this was the phenomenon of a convergence according to A. Sakharov, a prominent Russian physicist and laureate of Nobel Prize. He had offered to adopt the positive aspects either of socialism or of capitalism, and on that basis, he had conceived to improve contemporary societies. The physicist was subjected to massive ideological criticism. These accusations touched in any event with ergonomists and designers. While ergonomists and industrial designers carried out such an approach in the professional sphere, they did not think that the charges had been politically motivated. It was such a professional style of ergonomists' and designers' behavior that enabled them to achieve a high professional level in the planned economy and reach by many competence positions the world standards level of profession's acquirement in the domain of ergonomics and industrial design. Thus, the question posed at the start of the article has been answered and perhaps it is clear now why I deferred writing it.

For example, state industrial companies were not eager to use most of the VNIITE projects: no market – no interest to improve quality, no competition, and no reason to address new problems with new ideas. They had a state plan. "Plan is Law" – that was the motto of the planned economy. VNIITE found the back door through which to conquer the socialist economy by using the leverage: a "standard". The state standard (GOST) was the second vehicle after the state plan to control the centralized fashion economy. Designers, standard experts and ergonomists tried to legitimize design and ergonomics concepts as a standard for a particular field of industry (MUNIPOV et al. 1982).

We used the command-administrative management system of planned economy for the purpose of developing ergonomics. To facilitate the development of ergonomics, the USSR State Committee for Science and Technology held a meeting of its collegium in 1985. The agenda of the meeting was: "On Further Development of Ergonomics and Wide Use of Ergonomics Achievements in the National Economy". The main report of V. Munipov cited many examples of use of ergonomics' achievements in the western national economies, including one ergonomic program in Germany. H. Luczak took part in its development and implementation. That meeting was preceded by large preparatory work, which involved all-Union ministries and departments, the Councils of Ministries of the Union Republics, and the Academy of Sciences of the USSR. The collegium decided on a set of organizational and economic steps. Here a key role was assigned to ministries and departments, and to respective industrial and consumer goods manufacturers (MUNIPOV & ZINCHENKO 2001). Ergonomics then became an academic discipline, a subject of the candidate of sciences and doctoral dissertations. VNIITE organized master and doctorate postgraduate courses, and many talented people submitted their applications.

The important problems of ergonomics research were the interaction of "man-computer" and ergonomic development of automated systems of technological processes (ZINCHENKO & MUNIPOV 1989). In these cases, ergonomists recruited designers to participate in joint activities. We believe that these directions of research and development were central to the professional interests of Luczak (LUCZAK et al. 1991, SPRINGER et al. 1991).

Information science is often linked to a cognitive revolution; it is treated as a new cognitive discipline which has branched from many social, natural and technical sciences. Occasionally, the cognitive science is designated by the fairly polysemantic term "mind" which denotes reason, thinking, psyche and consciousness simultaneously. It is viewed as a sociological, psychological and natural science premise for the information science and for further development of computing engineering, including artificial intelligence. The revolutionary nature of the cognitive science is emphasized for the simple reason that it emerged by way of opposition to behaviorism and to the whole cycle of behavioral sciences that had held sway in the American humanities until the 1960s. In the Soviet Union, the notion of a cognitive revolution makes no sense because the opposition did not take on such acute forms (ZINCHENKO & MUNIPOV 1989). In the works of L. Vygotsky, S. Rubinstein, A. Leontiev and many other psychologists, cognitive processes were treated as forms of activity. It is on the works on the cultural-historical theory of psyche and consciousness developed by L. Vygotsky, on the psychological theory of activity expounded by A. Leontiev, A. Luria and A. Zaporozhets and on the theory of the physiology of activity advanced by N. Bernstein that ergonomics relies (N N 1981).

The category of activity is the most important one in the Russian system of ergonomic knowledge (N N 1970–1986, ZINCHENKO & MUNIPOV 1976). Psychology has amassed a wealth of factual material on the structure of human activity, thus making it possible to describe such essential components as the need, motives, tasks, actions and operations (the task integrates the goal and the conditions for its attainment). Psychology knows of facts demonstrating mutual transitions of these components. This discipline has also accumulated extensive evidence on the specific features of the two principal forms of human activity, the "external" and the "internal" ones, and on their mutual transitions. The "external" or object-related, practical activity is primary in relation to the "internal" – cognitive, mental activity. The dynamics of human activity follows a complex pattern, and so does the dynamics of regulatory psychic images (N N 1981).

The main type of activity of operators of automated control systems is working with information models, which are reflections of the state of the object of labor (the object of control), the system itself, the environment and modes of influencing them, organized in accordance with a definite system of rules. Physically, information models are realized with the aid of the means used to reflect information (indicators, displays, screens, etc).

Information models are not always easily related to reality. The operator's work with them frequently fails to satisfy the requirements of speed and precision. The main reason for this is that when devising information models engineers, as a rule, try to solve the problem of reflecting in it the system of interconnections of the object, while failing to take account of specific features of the psychological structure of man's work with that object. This ignores the obvious fact that information models are produced for operational work in the process of which the operator transforms the information they contain. Moreover, definite types of information models must correspond to each class of problems. The logic of problem solution determines the choice of principle on which the information model is structured.

The operator of a control system frequently has to carry out a great number of conversions of the information presented on the reflection devices, so as to move from the model to the reality and to reduce the information to a form fit for decision-making. Some intermediate results of these conversions are sometimes comprehended by the operator as images of reality, notions, schemes, models and behavior programs.

Evaluation of information, its analysis and generalization is effected on the basis of a comparison between the accepted information model and the inner conceptual-image model of the situation (control system) which the operator has developed in the process of instruction and training. The conceptual-image model is the product of the operator's comprehension of the existing situation keeping in mind the problems before him/her. The content of this model includes images and models of the real and projected situation, and the significance of the collection (of programs) of possible governing actions and executive reactions of the system. It also includes subjective (and frequently vaguely defined) elements like the notion of the purposes and criteria of the functioning of the system, motivations of activity, knowledge of the consequences of the decision taken, etc.

The information appears to the operator as a set of perceptive features, which are not evidently linked to conceptual features. The difficulties of moving from the perceptive to the conceptual features, on which the rules and instructions are based, pose the task of connecting the conceptual and the information models which make full use of operator's psychological possibilities in receiving and processing in formation and taking decisions.

The mediated perception of information creates a number of additional difficulties for the operator, who has to live in a real and simultaneously artificial world of signs, codes and symbols. He/she becomes accustomed to manipulating them. However, every model, especially a laconic one, contains some uncertainty, which repeatedly creates the possibility of either habituation or a stronger emotional impact than that of the real world.

Sometimes the operator becomes accustomed to the model and ceases to relate it to the real situation. This may result in a substitution of ostensible for genuine motivation of actions and loss of vigilance. In such instances, the objective perception of the model needs to be revived (N N 1970–1986, ZINCHENKO et al. 1973–1974, ZINCHENKO & MUNIPOV 1976).

It is not hard to notice that the modeling of cognitive processes by scientists of VNIITE and its importance to ergonomics had been defined by the same point of view about which H. Luczak wrote in his article "Utility of Cognitive Models" (2000): "the ergonomic approach of cognitive modeling is crucial for design of systems 'human-machine'". Distillation of this article and the main point of VNIITE's cycle of research can be expressed by the basic idea of another Luczak's article "Cognitive Modeling" (2000): "Cognitive modeling" can be understood as conceptual basis to describe the nature and the role of human cognition in the field of systems "human-machine". The problems stated above were solved by Luczak in the engineering context, that had been enriched by means of psychophysiological research, and furthermore, VNIITE's ergonomists psychology served as a basis, in which had been incorporated humanistic particles of engineering thought. Therefore, here we can talk about mutual enrichment of above approaches. And the main thing was that H. Luczak shared our views in this point, even in absence.

As I was exploring the creative scientific path of H. Luczak, I became aware, to an increasing extent, of the new sides of his activity representing the scientific and practical interest to me myself and for VNIITE. The institute undertook scientific and technical cooperation with the Institute of Labor in the city of Dresden (the former German Democratic Republic) which employed enough professionals. These were primarily psychologists and physiologists, and as a sidenote they currently successfully work in reunited Germany. However, there were also a number of scientists and managers at the Institute of Labor with conservative views who detested ergonomics. They repeated with conviction that the science of labor was traditionally developed in Germany and that it didn't need any reactionary bourgeois pseudo-scientific stream to which they were referred ergonomics as well.

Ergonomists of VNIITE dealt, for the first time, with the science of labor and, therefore, were eager to understand and adopt it. But that was more difficult than they had supposed. It was extremely difficult to understand in what there were a difference and a similarity it to ergonomics. Further confusion was added to this since, in some cases, the phrase "science of the labor" was used, and, in other cases, it was "the sciences of labor." My assertions that the labour science was just as ergonomics, but more universal discipline like all-embracing organizational science that had been distinguished by outstanding Russian thinker and scholar A. Bogdanov, literally met a hostile reception. My opponents weren't convinced by the assertion that ergonomics had arisen in the USSR in the 1920s after the October Revolution (1917). The first All-Union Initiative Conference on Scientific Organization of Labor and Production in 1921 examined the problem of human work as studied by different disciplines from specific angles of their own. Academician V. Bekhterev had pointed out: "The ultimate ideal of the labour problem is in such organization of the labour process that would yield a maximum of efficiency coupled with a minimum of health hazard, absence of fatigue and all-around personal development of the working people" (BEKHTEREV 1921).

Myasischev, who developed Bekhterev's ideas, suggested a special discipline named ergology. "A special discipline may be validated, first, by the fact that labor activity is not studied overall by any of the existing sciences; second, that it is outside the frame of reference of any of the existing subjects; and third, that this subject appears to be undoubtedly of exceptional importance" (MYASISCHEV 1921). Taking a positive view of the results of the First All-Russia Initiative Conference on Scientific Organization of Labor and Production, V. Bekhterev upheld Myasischev's idea of a special discipline on human work in 1922 and suggested the name for it, "ergonology" (BEKHTEREV 1922).

A Labor Research Department of Institute of Brain and Psychic Activity was equipped to deal with a wide range of problems. The Institute studied the work of radio and telegraph operators and physicians. These studies were carried out by special commissions comprised of experts in different areas of research and supervised by V. Bekhterev himself. There was a need for research to reconstruct workplaces, seats and labor conditions. This was the first ergonomics research (N N 1983b).

V. Bekhterev and fellow researchers devised a project for setting up an Institute of Ergonology. In 1920, the plan for the new Institute was submitted to the Petrograd Trade-Union Council, which approved the proposal. However, the project failed due to various objective reasons. V. Bekhterev was the chief of Petrograd's Department of USSR's Psychotechnics Society.

This didn't damp the zeal of my German critics who had accused me of dragging of tainted bourgeois fabrications to the healthy soil of socialist society. Sometimes I was on the edge of despair.

Being in a situation close to the severance of relations with the Institute of Labor, H. Luczak helped me again, without even being aware of it. During reading translations of his works and analyzing even separate provisions and observations of them I gained a deeper comprehension of what the science of labour was, and most importantly, I convinced myself in my rightness in a dispute with German colleagues from the former GDR. Resting upon Luczak's opinion, I confidently led a discussion with them and suggested a compromising solution out of this situation, which arranged all. However, I must stress that I reached the final understanding of the science of labor and its relationship with ergonomics only after studying a brilliant article of Luczak's "Arbeitswissenschaft in Germany". In the latter part of the article, he makes a number of criticisms of labor science professionals as well as other scientists of the former GDR, with whom I fully agree. By the way, I should note that I subjected to more stringent criticism.

Examination of the article allowed to conclude that the science of labor in Germany, and sciences studied labor in the Soviet Union in 1920s through the beginning of 1930s have had common roots in selected areas and phases of their development. No one had explored this interesting historical parallel. The difference between these areas of study was only in a single, but significant point. Understanding of interdisciplinarity or better to say multidisciplinarity science of labor applied in Germany, said Luczak, became to spread roughly from the mid-1920s, thanks to some authors (Giese, Lipman, Riedel et al.), but difficulties of integrating of the different approaches and their merger into one science had been not discussed at a serious level. In the Soviet Union in those years there was just strong trend to integration and its methodological and scientific issues had discussed at a sufficiently high professional level. Ergonology (BEKHTEREV 1922), which had already been dealt with, psychotechnics (N N 1983b) and labour protection (N N 1983b), served as the centre of attraction of such integration. Disclosure of the topic of their development and their interactions would be the task of special studies, reported in other articles. Author will portray further with a few strokes what is the fact of the matter.

Regarding psychotechnics, its leader in the USSR I. Shpilrein had a classical psychological education at the University of Leipzig up to 1917. Influenced by the works of H.Munsterberg and through personal communication with W. Stern he chose to specialize in "psychotechnics". L. Vygotsky, based on his historical analysis, argued that psychotechnics hadn't even been designed in Russia before the revolution. From the start psychotechnics became a scientific movement that spread all over the country. The scientific school of psychotechnics was founded by I.N. Shpielrein, L.S. Vygotsky and S.G. Gellerstein. This school of thought developed under the influence of the ideas of G. Munsterberg, W. Stern, F. Taylor and some Russian psychologists and physiologists (N.A. Bernstein, I.P. Pavlov, I.M. Sechenov, A.A. Ukhtomsky). The methodological foundations of the school were established by L. Vygotsky and served as the central pillar of his most important work "Istoricheskii smysl psihologicheskogo krizisa". Presented in the form of the dialogue-in-absence of Vygotsky L. with H. Munsterberg, whose ideas about psychotechnics had been developed by this Russian psychologist (MUNIPOV 2006, VYGOTSKY 1930).

As a result of this analysis, the author came to the same philosophical assumptions of the study of labor, about which had written Luczak. Relevant scientific review of the concept of "labor", he suggested, could be found in the philosophical writings of J. Fichte, I. Kant, G. Gegel and K. Marx. For the aim of solving the problem of integration of various disciplines into psychotechnics, S. Gellerstein and I. Shpielrein used the Gize's conceptions about "psychotechnics of subject" and "psychotechnics of object" that were mentioned in Luczak's article. Psychotechnics used Lipman's works for the development of its theory as well as practice, and Lipman's professiographic questionnaire (in Shpielrein's translation) was extremely popular in the USSR (MUNIPOV 2006).

Considering the question of the possible involvement of a psychotechnics expert in tool design "as an active collaborator in designing of basic idea of this or that tool" and not just in discharging the function of psychophysiological control and appraisal of already designed tools, Gellerstein in 1932 came to an idea consonant with present-day approach in ergonomics. With reference to such investigations, he wrote that in this particular case psychotechnics transcended its boundaries and thus would have to change its name. These investigations mirrored the need for a multidisciplinary approach (GELLERSTEIN 1932).

Finally, the third central of the attraction of integration processes in the study of labour was labor protection. In the 1920s Bernstein made a productive attempt at approaching many vital problems of human work optimisation for system-structural positions which crystallized in his mind during studies into the physiological mechanism of motor skills development and regulation.

Optimization of these systems of production's implements and the operator of these implements cannot be reduced to just the job of fitting the man to the machine. Berstein showed that such an approach to the problem was narrow, an approach that was tradional and dominated in work physiology and psychology in the 1920s and 1930s. "Occupation selection", the scientist pointed out, "is far not flexible weapon; its applicability is limited by a modest scope of natural biological variations. If the worker cannot be fitted to the implement and the environment, then both the implement and the environment should be fitted to the worker" (BERNSTEIN 1930). Such basic premises found some sorts of materialization, one of which dealt with the psychophysiological reconstruction of the tram-driver's workplace and seat. Bernstein carried out this investigation. This was the second ergonomic study about the reconstruction of workplace and seat.

Hoping that multilevel approach to optimization of the above systems, coupled with labor protection, could be translated into reality in the 1930s, Bernstein vigorously opposed the trend when such optimization „frequently evolves into a well-nigh philanthropic household compromise, instead of becoming a ground work of standards and calculations for the entire operating system. "A labor protection worker" the scientist argued, "should, in reality, not readjust a design that has been made without his/her participation, but take an essential part in the design process itself" (BERNSTEIN 1930).

In the 1920s and 1930s, the USSR ran a far-flung network of psychophysiological laboratories at industrial enterprises. Typical of those years was the close cooperation among psychologists, physiologists, occupational health workers and engineering personnel (DOBROTVORSKY 1930, DOBROTVORSKY 1937). The cooperation also involved experts in industrial and safety engineering.

International recognition of Russian psychotechnics came in 1931 when International Conference on Psychotechnics was held in the city of Moscow at the time when psychotechnicans were being persecuted (MUNIPOV 2006). In the second half of the 1930s the ideological criticism of national psychotechnics annulled all their achievements and actually did away with the studies on the problem of labor in the USSR, including the newly born ergonology. In 1936, all psychotechnics laboratories dealing with vocational psychology and psychophysiology of labor were closed down; activity of the General Labor Institute and the corresponding local institutes was dramatically curtailed (MUNIPOV 2006).

The concept of human-centered design was formulated in the 1970s in VNIITE. However, that idea could not make a reality of good design in the USSR in view of total domination of technics-centered design in the country. Only once, starting from the rule of contraries, i.e., meticulously analyzing how the neglect of human-centered design had led to the frightful consequences, I was able to test principles and methods of human-centered design on the real object bearing in mind the Chernobyl disaster. In this case, design, building, operation and detection of the causes of the accident had taken place without ergonomists' participation. Taking into account experience of H. Luczak and other world ergonomists and prior to when I began to make an inquiry into the causes of the Chernobyl accident, I had also studied the technology of nuclear industry with the help of paid consultants from the USSR and other countries during two years. In December 1989, I prepared a report named "Human engineering analysis of Chernobyl Accident.", but at that time there was no possibility of publishing it in the USSR. I learned for the first time that an operative group under the ruling of the Central Committee of the Communist Party of the Soviet Union had been established and that this group had undertaken severe scrutiny of all publications concerning the Chernobyl accident. According to the decision of this operative group secret instructions were given. They ordered: "to intensify the propaganda measures directed towards the exposure of false insinuations of the bourgeois mass media and special organs about the events that took place at the Chernobyl nuclear power plant”.

I’m very grateful to M. Kumashiro, a well-known Japan ergonomist, as organizers of the 1st UOEN International Symposium and 1st Pan-Pacific Conference on Occupational Ergonomics (Kitakyusu, Japan, 10–13 July 1990) invited me to present a report, the content of which was unpredictable because nobody had previously spoken on this matter (MUNIPOV 1991). During my report there was silence in the crowded room, because the Japanese are very sensitive regarding everything relating to nuclear power. After I completed the presentation, there was total silence, which frightened me. For a moment an idea flashed in my head – perhaps the report had not been understood and had been poorly prepared. However, suddenly everyone rose in applause. My first foreign teacher, English ergonomist B. Shackel, came to me and said: “Vladimir, I can help you so that you’ll be famous across the world. I am a member of the editorial board of a journal ‘Nature’, popular among scientists across the world. I’d like to write a review on your report in which there will be a recommendation to print it, and to send it, along with your report, on e-mail of editor in chief. “ After I had accepted the offer, B. Shackel looked at me with an inquiring gaze during a few seconds of pause and then asked: “Are you not afraid that upon your return back to Russia they would throw you in jail?” My response was instant and clear: “I don’t want to have such a fame and there is no reason for my throwing into jail. I am sure that those who know at least something about the reasons of the Chernobyl disaster should contribute by applying his or her knowledge for clarification of what happened in reality. This is important not only for Russia but for the whole world this must not happen again.” B. Shackel shook my hand and sent all of the materials to the editor-in-chief of the above-mentioned journal. An Editorial Board decided to publish the report and already communicated the message about it to B. Shackel during the conference. Then the editorial board started to keep a mysterious silence, as told to me by an English ergonomist. However, it may be the subject of another article. Inter vivos of B. Shakel, I didn’t retell this story for ethical reasons and even more so not to publish the story that he had told. But today I decided to do so for two reasons. First, to recall with kind words my teacher in the field of ergonomics. Secondly, to underline the shared approach of H. Luczak and B. Shackel to my report, which was published in 1992 in the journal Applied Ergonomics (MUNIPOV 1992).

H. Luczak, not being aware of the positive assessment by B. Shackel of my report, publicly expressed a similar attitude to the report, speaking at the plenary session of the Congress of IEA. I am grateful to him for that. Finally, our professional approaches had matched. IEA’s President of the time B. Metz found me in a congress’ hall and exclaimed: “You have been quoted by a well-known ergonomist. This is your professional recognition. I am happy for you.” A few months later, H. Luczak made me a request to give a response on the official document, approved by IEA and prepared by a renowned famous ergonomist. I do not know why, but it contained some questionable ergonomic recommendations on the design and operation of atomic-power plants. Some parts of the document were superficial. I wrote about it to H. Luczak and had to refuse to give the response. First, the famous ergonomist had helped me on many issues. Second, while I had gotten a professional recognition, I thought that it was wrong immediately to oppose IEA. Moreover, IEA had done a lot that a state organization "VNIITE" could join IEA as a member, and almost all the IEA's presidents had given me their full support, so I might take part in the congresses of IEA.

This article and my heart cannot express everything that I could say about the Man and the Professional H. Luczak and the role he has played in VNIITE's activities and my personality. Sharing the opinion that man in the social phase of his evolution deserves a new name – a Wise and Human Man – Homo sapiens and humanitas – I would like to point out that specialists in ergonomics are among the first to deserve that title. H. Luczak is such a Man in my mind.

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35 Accessibility in Information Technology

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1 Definition and History

The term accessibility was originally not related to information technology and related appliances, but to building construction. The Civil Rights Act in the USA, passed in 1964, together with an increasing awareness of the problems many people were encountering with barriers to accessibility, led Congress to take a careful look at the problem in 1965 while considering the Vocational Rehabilitation Act Amendment. The Disability Civil Rights Movement, active since the 1960s and 1970s, finally led to ADA (Americans with Disabilities Act) of 1990. The milestones between these dates are less important than the origins of the term, Civil Rights Movement on the one hand and architecture on the other. Creating barrier-free access to public buildings for all people was the major goal.

During the further stages of the development until the enactment of the ADA, the scope has changed to cover "access" to e.g. employment, education, transportation or telecommunications. A number of federal laws of the USA preceded this legislation, setting the stage for a "barrier-free information age". In 1998, Congress amended the Rehabilitation Act to require federal agencies to make their electronic and information technology accessible to people with disabilities. Section 508 was enacted to eliminate barriers in information technology, to make available new opportunities for people with disabilities, and to encourage development of technologies that will help achieve these goals. The law applies to all federal agencies when they develop, procure, maintain, or use electronic and information technology.

As can be seen from this history, accessibility has been a matter of legislation applicable to the behavior of US federal agencies for the benefit of people with disabilities as defined by law. Other persons would or could benefit if a provision leads to a helpful feature. For example, one provision (Clause 1194.21 Software Applications and Operating Systems) requires alternative keyboard navigation, which is essential for people with vision impairments who cannot rely on pointing devices, such as a mouse. The outcome is that any operating system shall enable

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users to navigate through any information system via keyboard, an extremely useful feature for power users. Other users are likely to benefit from this feature because switching between the keyboard and the pointing device, if enforced by the software, means a higher mental workload in combination with a higher biomechanical load. Other provisions related to keyboard use by people with disabilities, e.g. the use of StickyKeys™ or SlowKeys™, help any user under various conditions. A study in the USA found that 60% of working-age adults can benefit from the use of accessible technologies because they experience mild impairments or difficulties when using current technologies (FORRESTER 2003).

On the other hand, following the interests of people with disabilities may conflict with the interests of other persons. Many examples for this can be found in the recommendations for color and contrast in the public space as issued by the Federal Ministry of Health in Germany with the goal of improving the visual conditions for the visually impaired (FMH 1996). In principle, the best colors for visually impaired people would be black and white, giving the maximum available contrast. Following such an advice would not only conflict with the interests of the majority of people, but also hamper persons suffering from photosensitive epilepsy under circumstances. This means, that without an appropriate definition of accessibility and its goals, even serving the interests of a limited target group, people with disabilities, may prove difficult.

To overcome such problems, the ISO Technical Committee on ergonomics, ISO TC 159 "Ergonomics" has discussed the issue and agreed in 2007 to use the following definition in future standardization work: "extent to which products, systems, services, environments or facilities can be used by people from a population with the widest range of capabilities to achieve a specified goal in a specified context of use". The phrase "barrier-free information age" was considered a good slogan for setting goals in legislation, but not realistic for describing the pathway.

2 Actions, Actors and Implications for Ergonomics

2.1 Role of Standardization

In relation to legislation, standardization plays different roles in different countries. Many standards organizations are private bodies in legal terms, and their documents are considered "recommendation". In certain cases, e.g. in the European Union, the legislator may ask such a body to issue a document to support essential requirements of laws. For the EU as well as for the countries belonging to EFTA, the European Commission mandates a standard to support a certain "Directive". After this document passes the relevant procedures ensuring the requirement of meeting the essential provisions of that directive, the standard can be formally announced in the Official Journal of the European Communities together with the indication of the directive in whose support the standard has been prepared. Through this act, a mandated European standard becomes a "Harmonized Standard". To prove the conformity with the requirements of the corresponding directives, the harmonized standard can be applied.

Other standards may become part of the legislation by referencing. In this case, the legislator accepts all or some provisions of a standard as part of a legal document.

Even if a standard is not referenced, in general, it is considered an "anticipated expertise" or "state-of-the-art", and can therefore be applied with priority. This is valid for most standards.

In consideration of "accessibility", legal provisions, e.g. those from ADA or its German equivalent, BGG ("Gesetz zur Gleichstellung behinderter Menschen"), (BGG 2002) may be supported by standardization as long as the recommendations of the documents under consideration do not conflict with the requirements laid down in legislation. This is also true for various requirements of Section 508, Subpart B "Technical Standards". Although this part of the law is named "standard", it contains detailed provisions of mandatory nature, e.g.: "Applications shall not override user selected contrast and color selections and other individual display attributes." Thus, standardization by bodies such as ISO shall consider detailed provisions of US law as well as potential requirements of European legislation in order to be generally acceptable.

The definition of accessibility by ISO TC 159 expands the addressees of the future provisions far beyond those considered by legislation. While standardization aims at making products, systems, services, environments or facilities usable for a wide population, the provisions of the legislation are applicable e.g. to "people who have physical or mental impairments that substantially limits one or more major life activities, has a record of such impairment, or is regarded as having such an impairment." (ADA 2008).

The German law is even more restrictive: "Humans are disabled, if their body function, mental ability or psychic state of health differs from the typical situation of their age with a high probability for more than six months, and therefore their participation in social life is impaired." (translation by the author). This means that, for example, an 80-year-old person with a high degree of hearing loss is to be considered not disabled. Since this person is likely also to suffer from a considerable loss in vision, in many respects concerning the participation in social life she or he is likely to be heavily impaired.

The definition of accessibility as adopted by standardization expands the range of people to be considered far beyond the target group of public laws. By adopting this definition, standardization also aims at changing generic ergonomic rules to a great extent as can be seen for example from the description of the target group for software accessibility (ISO 2008a):

"Therefore, accessibility addresses a widely defined group of users including:

- people with physical, sensory and cognitive impairments present at birth or acquired during life,

- elderly people who can benefit from new products and services but experience reduced physical, sensory and cognitive capacities,
- people with temporary disabilities, such as a person with a broken arm or someone who has forgotten his/her glasses, and
- people who experience difficulties in particular situations, such as a person who works in a noisy environment or has both hands occupied by other activities."

If this target group is adopted in analogy for all design purposes, and not just for software, a much bigger portion of humans is likely to benefit from provisions of standards developed in consideration of accessibility in comparison to those who benefit from current ergonomic concepts.

2.2 W3C – An Exceptional Standardization Body

Despite its age of less than 20 years, the World Wide Web Consortium (W3C), has gained a high level of importance in comparison to other bodies setting standards although it is not a regular organization for standardization. Directed by Tim Berners-Lee, who accounts for inventing the World Wide Web, W3C has published more than 110 "standards", called "W3C Recommendations" (Note: In difference to other standards bodies, this group focuses on a single object, developing Web standards.). Following one of the basic strategies of W3C, achieving the universality of the Web, the first set of guidelines Web Content Accessibility Guidelines 1.0 (WCAG-1.0) have been released in May 1999. The goal of these guidelines was expressed by Berners-Lee with the following sentences: "The power of the Web is in its universality. Access by everyone regardless of disability is an essential aspect." (BERNERS-LEE 2002).

Making the Web accessible was already required in 1996 by the US Department of Justice (DEPT. OF JUSTICE 1996): "The Internet is an excellent source of information and, of course, people with disabilities should have access to it as effectively as people without disabilities."

The W3C guidelines (WCAG 1.0) do not fully comply with the technical standards of Section 508. It is indicated which additional requirements shall be met for full compliance.

Currently, W3C is revising its guidelines and creating a new set of recommendations (WCAG 2.0). The individuals and organizations that use WCAG vary widely and include Web designers and developers, policy makers, purchasing agents, teachers, and students. In order to meet the varying needs, several layers of guidance are provided including overall "principles", general "guidelines", testable "success criteria" and a big collection of sufficient techniques, advisory techniques, and documented common failures with examples, resource links and code. The requirement is: "Anyone who wants to use the Web must have content that is:

- Perceivable – Information and user interface components must be presentable to users in ways they can perceive

This means that users must be able to perceive the information being presented (it can't be invisible to all of their senses)
- Operable – User interface components and navigation must be operable This means that users must be able to operate the interface (the interface cannot require interaction that a user cannot perform)
- Understandable – Information and the operation of user interface must be understandable.
  This means that users must be able to understand the information as well as the operation of the user interface (the content or operation cannot be beyond their understanding)
- Robust – Content must be robust enough that it can be interpreted reliably by a wide variety of user agents, including assistive technologies This means that users must be able to access the content as technologies advance (as technologies and user agents evolve, the content should remain accessible)" (W3C 2008).

Even if no other bodies would issue additional requirements/standards, just complying with Section 508 and WCAG 2.0 while creating an application will mean a great challenge for software designers who also want to comply with ergonomic principles like consistency. A further problem is created by differing opinions about "Web usability" and usability as such.

2.3 ISO TC 159 – Subcommittee 4 Ergonomics of Human System Interaction

2.3.1 Scope

The most extensive work in ergonomics of computer work has been performed by the subcommittee SC4 of ISO TC 159 which has been active since 1983. The scope of this group covers ergonomics standardization of the interaction between systems (often computer based) and the people who design, manufacture, use and maintain them. Areas of standardization include hardware ergonomics (including input, display and interactive devices), software ergonomics (including dialogue and interaction design) and human centred design processes and methods (including usability engineering and participative design methods).

2.3.2 Differences in the Application

The description of the scope of SC4 shows that all items of it require the consideration of accessibility, however, in different ways. Computer monitors, for example, can display different content so that some requirements for accessibility can be met using appropriate software, and only few users are likely to need different hardware. For these persons, the hardware can be installed separately. Whereas input devices like mice or trackballs may partly or fully fail, e.g. because of the missing abilities of the upper extremities needed to operate these devices. The same is true if the hands of the user are needed for another task. The solution in such cases can be using alternative devices, assistive devices if needed or a combination of alternative devices. Thus, the device itself does not need to be "accessible", but the work system.

For the work environment such solutions may not work because the users for whom the accessibility features are important may be unknown while creating that environment. The best examples for this are named in the original documents for accessibility in architecture. Thus, SC4 documents related to the ergonomic design of the workspace, e.g. those dealing with the design of control centres, need either to include accessibility related provisions, or at least not inhibit the realization of features relevant for accessibility.

The task is completely different for software, especially for systems with unspecified users. Websites and the information presented there are the best examples for this aspect. Not surprisingly, the US-lawmaker has dealt with questions related to Web and accessibility already during the initiation of the Web in the 1990s. Many accessibility issues have to be considered during the design phase because later corrections may not be possible.

2.3.3 Accessibility for Human-System Interaction in General

SC4 has started a variety of work items related to accessibility. The most advanced work item is ISO 9241–171 "Guidance on software accessibility" (ISO 2008a). Although this standard has been written to address accessibility issues about half of its provisions are likely to help all users in their daily work. Even claiming that this standard is relevant for daily life seems justified because the quality of software may affect many life activities including the use of environments, services, products and information, and not just the use of computers. The term accessibility as defined in this standard emphasises the goals of maximising the number of users and striving to increase the level of usability that these users experience.

Not limited to, but also relevant for accessibility are the projects of SC4 related to haptic/tactile interfaces (e.g. project ISO 9241–920). Haptic interfaces refer to technology that interfaces the user via the sense of touch by applying forces, vibrations and/or motions to the user. In ergonomic research, haptics or "the science of touch" is surprisingly underrepresented in comparison to the possibilities to encode information, e.g. by properties such as material (hardness), surface (temperature), geometry (size) or by temporal properties (motion, acceleration).

The work on this project will not only create new standards but also an understanding for haptics. The sense of touch develops as the first antenna of an embryo and makes the environment intelligible long before the auditory system. In difference to the visual and the auditory system that can sense only one physical dimension (light or sound), the sense of touch can handle combinations of up to ten dimensions simultaneously (CAKIR 1996). The real power of haptics in barely understood in ergonomics. In other areas, e.g. virtual reality applications, the utilization of this sense is considered a key success factor. Combined with vision, e.g. for haptic visualization of scientific data, the ability of humans to sense complex information is substantially enhanced (TAYLOR 2005). In addition, haptics is the only sense of bimodal nature, i.e. the same organ can accomplish sensing and modifying an object at the same time. This allows direct and immediate control over simulations and remote operations with direct and immediate sensing of the results.

Although utilizing the sense of touch in computer sciences not a new issue, touch and related capabilities such as kinaesthesia are probably the most underrated human abilities. This is also true for ergonomics. Thus, dealing with haptics for purposes related to accessibility is likely to enhance our understanding of the only sense we cannot live without.

2.3.4 Accessibility for ICT Equipment and Services

The series ISO 9241 contains a specific part dealing with accessibility issues for ICT (ISO 2008b). The goal of this part is to help developers enable ICT equipment and services (and forthcoming novel or innovative equipment and services) so that they can be used by the widest range of people, regardless of their capabilities or disabilities, limitations or culture. The user groups addressed in this standard are the same as with ISO 9241-171. The standard provides guidelines for improving the accessibility of ICT equipment and services such that they will have wider accessibility for use at work, in the home, and in mobile and public environments. It covers issues associated with the design of equipment and services for people with a wide range of sensory, physical and cognitive abilities, including those who are temporarily disabled, and the elderly.

The standard specifies four levels of approaches to be considered in order to take account of the variation in user and use characteristics beginning with products or services designed for use by the user population without need for any modification or the connection of assistive technologies and ending with instances where assistive technologies are needed.

2.3.5 Accessibility for Input Devices

Input devices, e.g. mice or tablets, are the only real interactive components of systems. Generally speaking, an input device is a sensor that can detect changes in user behaviour (gestures, moving fingers, etc.) and transform them into signals to be interpreted by the interactive system. Some input devices can also display information, e.g. as a haptic interface (s. above). While in computer literature an input device is treated equally with other "periphery" like a visual display or a printer, its role reaches far beyond. Any change of the user behaviour and any combination of detectable changes can be used to create input.

This fact gives us the chance to develop a different concept for utilizing input devices for accessibility purposes. The basic concept, the concept of fit, has been formulated in ISO 9241-5:1998 (ISO 1998): "Design and selection equipment requires a fit to be achieved between a range of task requirements and the needs of users. The concept of fit as defined in ISO 9241-5:1998 concerns the extent to which equipment (visual display units, input devices, etc.) can accommodate individual users' needs." (ISO 9241-400:2007). The concept of fit has introduced a major deviation from usual (good) practice in ergonomics where the intended user population is limited to the 5th percentile to 95th percentile of the real population. It must be noted, that even this limited approach has improved the design of technical products and workplaces substantially. However, it is not easy to find literature about possible solutions for the rest of the people. This "rest" is being deemed negligible because most people tend to calculate the proportion of those affected to around 10%. This assumption is only true if one dimension is relevant, e.g. the height of the legroom of a desk. If two independent dimensions are to be considered, the percentage rises to 19. If four dimensions are relevant for a design, fit can be achieved for 65% of the user population at best.

The concept of fit is broadened for the utilization of input devices as follows: "Good fit is needed for the intended user population, including users with special needs, e.g. people with disabilities, if the use of a certain device is not limited to a specified user population and task. Since a variety of input devices exists that may enable a user to achieve the same usability for the same task by creating input through different bodily abilities (e.g. hand, foot, speech or eye control) the required fit can be achieved by utilizing any device that offers the required level of usability. Depending on the character of the special needs, a combination of different devices may be necessary, e.g. a foot- and an eye-controlled input device instead of a mouse for a person who cannot use his or her hands for whatever reason." (ISO 2007).

The major deviation of this concept from the current practice consists in its principle. Instead of considering a certain type of disability, the starting point of the concept is the task to be accomplished. Thus, achieving good fit for a certain person or a group of users may require different devices or combinations of them depending on the task. Goals that the users of input devices need to achieve could be defined as high-level tasks such as "word processing" or "multimedia". A definition in this level, however, would be too abstract to design, test or select a device. For this reason, the standard specifies "task primitives" such as "pointing", "dragging" or "code input" whereas task primitive is a fundamental action associated with using an input device.

2.4 Legislation and Accessibility

2.4.1 Revision of Section 508

Currently, the U.S. Access Board is preparing a revision of the Section 508 Standards on the basis of a report by the Telecommunications and Electronic & Information Technology Advisory Committee (TEITAC), a formal federal advisory committee. This report details recommended changes to both the substance and the structure of the standards and guidelines. Products covered include technologies used for communication, computing, storage, duplication, and production, among others. Access is addressed for all types of disabilities, including those that are sensory, physical, speech-related, or cognitive in nature.

Due to the importance of the intended revision, representatives from three other countries (Australia, Canada, Japan) and the European Commission, also developing and implementing accessibility standards, were included in the consultations of TEITAC (ACCESS BOARD 2008). Briefly said, the report proposes standards needed so that people with disabilities might achieve access and use of information comparable to that of people without disabilities. However, the existing standards are criticized while setting the goals of the revision: "The Committee recognizes that Federal agencies and consumers with disabilities need to benefit from advances in technology. The pace of technological advancement in ICT is rapid and the level of innovation is high. In this environment, a static standard consisting of design specification and fixed checklists would tend to stifle innovation and to delay the availability of technology advancements to people with disabilities." (ACCESS BOARD 2008).

2.4.2 European Union – European Commission

Accessibility in general does not appear in the list of the top level European policies (EUROPEAN COMMISSION 2008a). With regard to information technology, the focus lies on eAccessibility, i.e. a short term representing "Accessible Information and Communication Technologies (ICT)". eAccessibility is deemed to contribute to the implementation of the " i2010 – A European Information Society for growth and employment "initiative launched in June 2005, that presents a new strategic framework and broad policy orientations to promote an open and competitive digital economy, emphasising ICT as a driver of inclusion and quality of life. "The Commission has the ambitious objective of achieving an 'Information Society for All', promoting an inclusive digital society that provides opportunities for all and minimises the risk of exclusion." (EUROPEAN COMMISSION 2005). In difference to ADA, this policy is also justified by the demographic shift as the Commission states "making the benefits of ICT available to the widest possible number of people is a social, ethical and political imperative" (ibid.). "Older people" are named as a target group of the initiative.

Following the communication of the initiative, the EC has decided to collect data from the member states through a policy survey including new evaluation methods and procedures, benchmarking, data collection and identification of best practices. The results of this action demonstrate that Europe is far from a concerted action (EUROPEAN COMMISSION 2008b). A strong indication for this is the statement "So it is difficult to draw any firm conclusion on the likely aggregate impact on eAccessibility across the EU of these Member State initiatives." (ibid.). Even the consideration of "Web accessibility" that has been efficiently addressed by W3C in 1999, and emphasized as a major target by the US authorities even much earlier, seems not adequate: "Finally, respondents (Member States) also described how the programme concerning web accessibility is organised in their country, referring to any codes of practice and guidelines and specifying the ministry responsible for eAccessibility. Again there is considerable variety in how this is structured; but in only about 25% of cases does there appear to be a clear locus of overall responsibility for ensuring the implementation of an eAccessibility plan."

2.4.3 Legislation in Germany and German Speaking Countries

The equivalent German law to ADA was issued in the year 2002 with a title exactly describing its goal: Behindertengleichstellungsgesetz (BGG) = Act on Equal Opportunities for Persons with Disabilities. Laws with similar titles and the same goal exist in Austria, Switzerland and Liechtenstein. One of the important topics is "barrier-free" ICT. Its provisions are valid for all bodies representing public authorities including federal administration, local state administration and all associated bodies. An ordinance under this law, BITV = Ordinance to create barrier-free information technology, regulates Web design, design of intranets with public access, and graphical user interfaces that can be used by the public. The provisions base on WCAG 1.0.

As can be seen from the text, the law and the ordinance are much simpler than the US legislation. Whether or not this means a better help for those affected is not easy to judge because the regulations in the USA influence all operating systems of computers, a majority of application programs and a variety of products sold and used in Germany even if they address US federal agencies only. And German vendors who plan to offer their products in North America consider US guidance.

3 Conclusion and Outlook

Accessibility in general, and also accessibility in ICT is likely to remain an important topic for the next decades. Even in the USA where the history reaches 40 years back and the initiative was born out of a very powerful political movement (Civil Rights Movement), the current situation can be characterized as a stage of policy finding. In Europe, several countries have published legal provisions in consideration of accessibility but concerning the harmonization far from the power of the concerted action in standardization related to the Single Market during the 1980s and 1990s. The public consultation of the EC on Web accessibility has closed on 7 September 2008. This means, that the development of a clear policy is likely to take many further years.

In standardization, the ISO Technical Committee on Ergonomics has taken a decision that expands the target group far beyond the addressees of existing legislation, and also beyond the usual target groups in ergonomics including ergonomic standards.

This situation means that much work needs to be done in research and development including fundamentals of workplace, hardware and software ergonomics. It provides a unique opportunity for ergonomists to participate in a long term project with a potential to change private and working life of all people substantially. Integrating accessibility into of products and services is a great challenge for all who plan, design or produce.

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36 Ergonomics and Design

Heiner Bubb, Birgit Spanner-Ulmer

1 Introduction

Product development has a long history with many influences from a multitude of disciplines. Up to the 19th century, products were engineered and produced by craftsmen or in manufactories. In the process of industrialization, engineering and production were separated which led the development of products to a new era.

The primary goal of a development process has always been to create a product with specific functions. In addition to the function, the costs, the manufacturing, and the service of a product, there are two very important disciplines that contribute to a successful product: design and ergonomics.

The esthetical design of products was considered to be important from the very beginning (e.g. the ornamentation on historical industrial products). But up to the 1920s, architects were assigned to shape industrial products. In the 1970s the “shapers” or “stylists” became industrial designers.

This discipline of ergonomics, often also called human factors, was first specified by Jastrzebowski in the mid 19th century. He defined the goal of this new discipline as to explore human work and apply the results to enhance the working conditions. Not since at least the 1950s ergonomics also intended to create products with better usability and less health risks through human-oriented design. Since the 1960s, many technical universities in most industrial nations have founded professorships or institutes for ergonomics. The ergonomic research and development of products became a permanent institution. Even in advertisement and product specifications, the term “ergonomic” is used very often.

1.1 Comfort and Discomfort

Nowadays, esthetical issues and comfortable handling of all types of machines and software are fundamental influences for economical success. Recent research indicated two influencing factors for comfort: aspects of pleasure and aspects of suffering (ZHANG et al. 1996). These parameters were called comfort and discomfort (Fig. 36.1).

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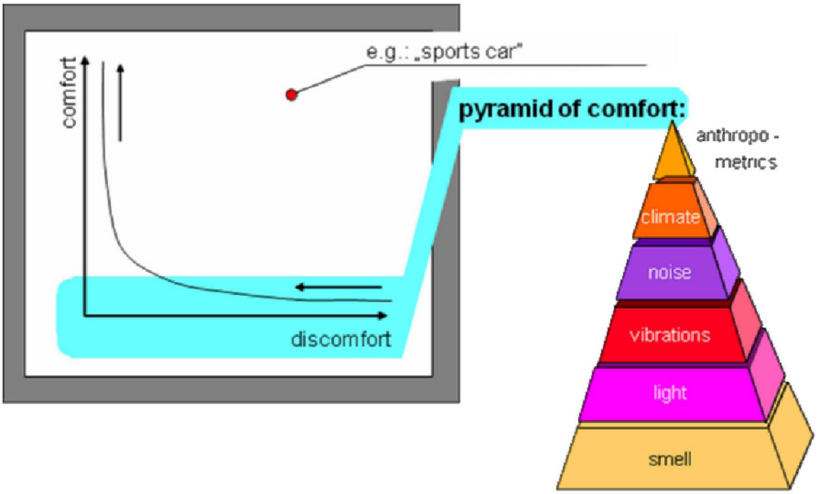

Fig. 36.1: Diagram of comfort and discomfort and the pyramid of comfort

The factors contributing to pleasure are very hard to determine, though the existence of objective relations is assumed. Research done in the field of cognitive esthetics discovered that objects are recognized as pleasant when they have a certain degree of complexity and a high recognition rate (KERSTEN 2006). According to this last implication, average items should be considered most attractive. But studies concerning the attractiveness of faces showed that systematic deviations from the average could increase pleasure (LANGOIS & ROGGMAN 1990, RHODES & TREMARAN 1996).

The negative aspects or the discomfort can be measured with the usual psychophysical methods. Psychophysics puts a physical stimulus and the human perception in relation. In accordance with psychophysical research results (ZHANG et al. 1996), the pyramid of comfort can be defined. The lower items are most important and are required to be designed satisfactorily before the upper items come into play.

The attractivity of a product brings the issue of usability into the focus of product design. Usability can be described with the comfort/discomfort-model too. The negative aspects can be measured and decreased with ergonomic methods. On the contrary, comfort is a very artistic, non-science-based concept. This is the cause of the exciting contrast between scientifically oriented ergonomics and artistically oriented industrial design.

1.2 Form Follows Function?

Products have always needed a certain form. Until the late 1950s, this problem was solved by design-talented engineers. But soon the intention was to professionalize design. First influences came from architecture. After a debate about the relations of functional forms and ornaments, the design group Bauhaus made proposals for industrial products. From 1919 to 1933 the school of Bauhaus, founded by the architect Walter Gropius, created buildings, furniture, cars, home appliances and many other products. Commercial issues outweighed esthetical requests. “Form without ornaments”, as the recommendation of this time goes, led to standardized and simple forms built for mass production. For a long time minimalistic forms were seen as good designs (REESE 2005). This changed in the 1960s, when emotion became dominant in the design process. The question of what is meant by function has became more versatile. In addition to the technical function, the practical function for the user, the esthetical and symbolical function for the designer and the pleasing and emotional function for the customer has recieved more attention (Fig. 36.2). These aspects are important not least because customers who own everything they need have to be seduced to buy new products by inducing new desires in them (STEINFELD 2006).

Fig. 36.2: Form follows function: classic door handle with ornaments, door handle in Bauhaus style, modern door handle

Nowadays it is common sense that functionality is a complex concept. Even a screwdriver can become a sign of good taste, wealth, or technical expertise, depending on its design. The courage to use ornaments representing the meaning of emotions is becoming more and more visible. The right design gives a product its “soul” which can awaken the customers’ desire for the product (OSTLE 2003). An obvious example for this development is the automotive market, where surfaces represent emotions (RIEGSINGER 2006).

2 Automotive Exterior Styling as an Example for Ergonomics and Design

The development of products is not only influenced by the era but also by technical possibilities and trends. The automotive sector shows this very clearly. The character of an automobile is mainly defined by the exterior design. A short overview of car exterior design is given in this section (BUBB 2007).

The form of automobiles was initially based on the design of coaches. The Daimler “Mercedes” from 1901 is deemed to be the first construction called "autocar". Many of the automobiles to follow have been based on this concept, e.g. the Ford Model T (Fig. 36.3). From the 1920s and onward, the technical possibilities increased and the needs of the passengers came to the fore. This led to a passenger cabin, protecting the passengers against wind and weather. A place for the transportation of suitcases and bags was added behind the passenger cabin.

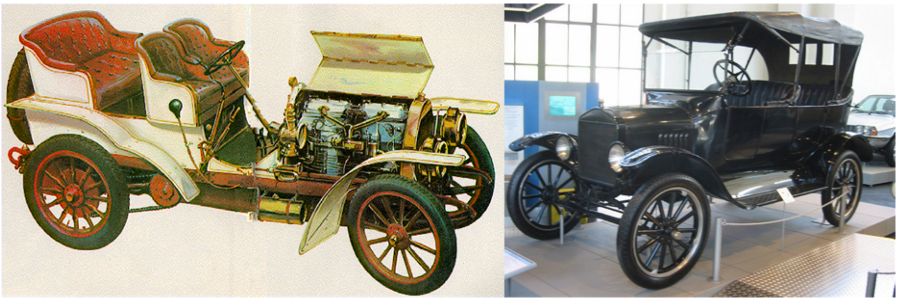

Fig. 36.3: The Daimler "Mercedes" and the Ford Model T

During the 1930s and 1940s, cars received increasingly distinguishable exteriors which left the realm of the technical constraints. Radiator grills, front windshields, integrated radiators and streamlined forms aimed at the customers' emotions.

Influenced by the design concept of the tailfin from the United States, in the 1960s the trapezium shape came into vogue. The panorama windshield is part of this style concept too. The automobiles of this era have an excellent panoramic vision, caused by the thin mullions and the low belt line.

Beginning from the 1970s the main design impacts were no longer created exclusively in the United States, but also in Europe. A main idea was the Two-Box-Design, introduced by the VW Golf (Fig. 36.4). This replaced the classic Three-Box-Design of engine bay, passenger cabin and rear trunk by combining the cabin and the trunk into one flexible interior space. Other rising trends were minivans, e.g. the Renault Espace or the Chrysler Voyager.

Fig. 36.4: The Volkswagen Golf

Nowadays the design of cars is influenced, among other things, by safety features and equipment. Airbags, crush zones, the protection of pedestrians and crash tests are some elements, which cause bigger A-, B- and C-Pillars, a higher front end, a higher belt line and bigger cars all in all. In summary, this led to worse vision conditions and feeling of security. Sports utility vehicles (SUVs), multi purpose vehicles (MPVs) and the individualization of the automotive classes are further trends of today’s world.

Some of the big trends in the history of car development pertain to the acceleration of body height growth, the change of vision conditions, and the spatial perception. The exterior styling is a main element of the design or styling of a car, for which some ergonomic issues are relevant. The interior styling is also a main design element, but more strongly related to ergonomics.

2.1 Package Design

The term package describes the main dimensions that define a car concept. This can be shown by the influence the distance of the Seating Reference Point R-Point from the ground has on other car dimensions. The more distant the R-Point is from the ground, the more upright the seating position has to be. This is due to the fact that the driver sitting in the car has to be able to overlook the area in front of his car. An upright sitting posture influences other dimensions, e.g. a more horizontal steering wheel and a low distance between the R-Point and the Accelerator Heel Point. If on the other hand the R-Point is very low like in a sports car, the driver’s position resembles more that of a lying person, with a more vertical steering wheel and a high distance between the R-Point and the Accelerator Heel Point. The choice of the R-Point therefore has enormous influence on other car dimensions and hence on the whole concept of the car.

2.2 Ergonomic Requirements for Entry and Exit

Some aspects belonging to ergonomics and exterior design are the entry and the exit of a car, the door handles and opening functions, the protection of the passengers and the protection of other traffic participants. The entry and exit as one of the first comfort perceptions of a vehicle for drivers and passengers is an example where close cooperation between ergonomic and design experts is essential. (RIGL 2005, CHEREDNICHENKO et al. 2006). Besides interindividual differences, the situation and environment where the entry and exit situation takes place strongly influence the requirements. For example, it makes a big difference if there is a curbstone beside the car, if the person has to carry a load or an umbrella, if the parking slot is confined, or if the person is wearing certain clothes like a skirt (Fig. 36.5). To achieve good results, the upper edge of the door frame should be as high as possible. The side bolster should be as small as possible for getting in and off, but at the same time ensure stability when driving. The door sill should be as low as possible and the seating position should be high enough for comfortable entry and exit. The angle of the opened door and the shape of the doorway are important design elements. Door Concepts like doors fixed at the rear end or sliding doors can be interesting options.

Fig. 36.5: The evaluation of getting into and out of a car

3 Automotive Interior Styling as an Example for Ergonomics and Design

The interior has other requirements for design and ergonomics than the exterior. The interior design is very important to the companies, too, taking into consideration that the exterior is perceived first but the interior is closer to the driver. The ergonomic aspects of interior design are more numerous and more versatile than those of the exterior, caused by the direct and frequent interaction of the driver with the automobile interior.

The interior styling of automobiles is a very good example to show the relation between ergonomics and design. The design issue has been handled from the mid 20th century, as described before. Ergonomic experts began to assist the development of the interior in the same era. The main elements required for driving a car are the steering wheel, the seat, the pedals, the gearshift lever, and the windows. These elements have to be designed in a way that the driver can reach and safely use them. Subsequent standards were set, and today these components are basically designed according to the same standards. Further aspects of the interior styling, like the layout of storage areas, the materials and the spatial perception are more design-oriented than ergonomic topics. Important topics of automobile ergonomics are information and entertainment systems, which are growing rapidly in number and functionalities. Things like car hifi, navigation system, driver assistance systems etc. have to be designed in an ergonomic and esthetical way.

The driver interacts with many of his senses with the automobile, which will be described in the following section. Aspects of multimodality and human-machine-interaction are described below and will be completed by several design rules the developer can work with.

3.1 The Human Senses

Of the five human senses, three are used to convey information to the user, namely seeing, hearing and feeling. The other two, smelling and tasting, are for several reasons not considered apt to be applied in human machine interfaces. The most important sense is the visual sense. About 80% of the incoming information is received by the eye. The auditory sense is of a similar importance, it is better suited for certain information and warnings. Haptic interactions complete the human-machine-interface in a modern car.

3.1.1 Visual Design

The aspects of visual design and ergonomics are very versatile. The vision during night, the vision conditions limited by different window designs, the ability to identify the instruments and the vision through mirrors are main topics when designing the interior. For example the vision conditions to the front, the rear and the sides were very bad in the cars of the early 20th century. The panorama windows of the 1960s produced ideal proportions for looking out of the car, and later developments foiled this development with the need to integrate a number of safety functions (Fig. 36.6).

Fig. 36.6: Vision conditions during a parking activity; on top a car of the 1930s (BMW 335), in the middle a car of the 1960s (BMW 2000), on the bottom a present car (BMW 540i)

To enable the driver to read off the analog and digital displays, research has contributed to developing a variety of norms, defining display type choices, minimum sizes, contrasts, and other visual parameters.

3.1.2 Acoustical Design

Auditory signals can convey information. Such signals can intentionally be used to improve human-machine interaction when designing a product. Cars are one of the most interesting products auditory signals are used in. In the last decades the majority of the in-car auditory signals were very similar: easy sinusoidal signals with rectangular envelopes (HIERSEMANN et al. 2007). They do not have a meaning or a character to recognize. Only a few signals of very new models have an instrumental timbre which is more pleasant. However, none of the existing signals convey information. The consequences of good or bad designs can be very far-reaching, e.g. the drivers can be frightened or the signals could cause confusion. According to experiences with medical equipment and robotic systems, this can be improved in the future (MÜHLSTEDT et al. 2007).

New improving technologies like modern sound-processing digital signal processors (DSPs) or flash memory are upcoming possibilities to transmit data to the user. With an increasing number of driving assistant systems the need for signals that inform the driver is growing. These signals have to be different to allow them to be connected to a single event. The timbre of the signals should be appealing.

Two groups of signals can be distinguished: warning signals and informational signals. Warning signals have to be standardized and should be simple sinusoidal or comparable signals. Parameters, given to define these signals, other informational-like signals can be more complex, e.g. by using earcons, auditory icons and metaphoric sounds as well as speech signals (MCKEOWN 2005). Those signals can improve a human machine interface when conveying information and have an esthetical quality. Considering established design methodologies (DATECH 2006), the creation of the signals should be structured and methodical. Therefore, main elements are the meaning of a signal, which should be recognizable auditory, and the urgency, which should be determined in detail (Fig. 36.7). The frequency of the signals defines other acoustical parameters, as well as the form of modulation (none, repeated, repeatingly changing). The other main aspect of a sound signal is the esthetic shape of the sound.

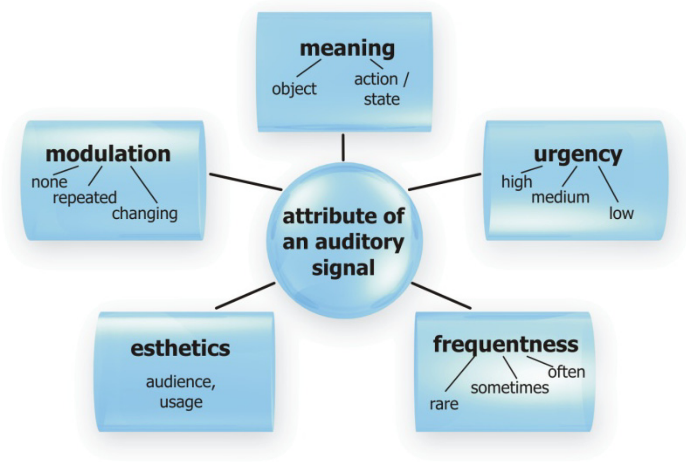

Fig. 36.7: Important elements of informational auditory signals

More research has to be done for the informational as well as the warning signals. The warning signals must be determined through specific instructions for how to form the signals, containing signal levels, frequencies, envelopes, signal-to-noise-ratios and influences on other acoustical systems like navigation or radio.

For the second group a methodically structured handbook, which the designer or engineer can use to create such signals, has to be developed (SUIED et al. 2005). Questions regarding the frequency of use, the length of the signals, interaction with other auditory systems or the use of modulated signals have to be answered (EDWORTHY 1994). Possibilities to group a higher quantity of signals or how to code the urgency are problems not yet solved either.

3.1.3 Haptic Design

The third sense applied in human machine interfaces is the haptic, more specifically the tactile sense of the skin. The human tactile sense can deliver information on pressure and vibration of objects in contact with the skin. Although this type of sensory input is processed very fast, it is still rarely used in the automobile setting. Some modern systems use vibrating seats or steering wheels to inform the driver if he unintentionally leaves his lane (Lane Departure Warning).

Apart from receiving information from in-car systems, the tactile sense contributes strongly to the quality perception of the car. This is valid for the exterior (design of surfaces, gaps) and the interior (design of actuators like control wheels and buttons). It is important to pay consideration to the design of all elements the driver touches or uses to interact with the car. Modern cars commonly have a reduced number of actuators due to the integration of different systems into one user interface (see below). Therefore, this reduced number of actuators gains significance in respect to the driver's perception of the car and needs a more refined design than before. Research has shown that force-deflexion-diagrams of rotatory actuators only partly describe their haptic perception and that the integral of the torque over the rotational angle strongly correlates with the haptic perception of actuators like the turning wheel in the BMW 7 series (REISINGER et al. 2007).

3.2 Human-Machine-Interfaces of Intelligent Transportation Systems

A very important goal of automotive ergonomics is the reduction of accidents (SPANNER-ULMER 2008). Human error is the most common cause for accidents. In the human machine interface, the human subsystem is characterized by its three stages of information procession: perception, processing and action. All three stages are subject to limits of the human physiology and psychology, especially attention and its distribution among different tasks (WICKENS 2005). In modern automobiles, attention has to be divided between different tasks (GEISER 1985), the primary task always being driving (divided into navigation, guidance and stabilization). If the secondary (e.g. shifting gear, activating indicator lights, dimming headlights) or tertiary tasks (e.g. using the radio or the climate controls) are consuming too much attention, the primary task may suffer a lack of attention which can lead to dangerous incidents or even accidents. Therefore, all secondary and tertiary tasks have to be ergonomically designed to require as little attention as possible and to not interfere with the primary task.

The radio was the only instrument of tertiary driving functions for a long time, combining display, controls and an entertaining function. Over the last decades, many intelligent transportation systems (ITS) were developed. Hence, the number of displays and controls increased immensely. The systems are separated in advanced driver assistance systems (ADAS) and in-vehicle information systems (IVIS), which both have an impact on cockpit design (Fig. 36.8). The ADAS assist the driver in main driving functions, like the Anti-lock Brake System (ABS), the Electronical Stability Program (ESP) and the Adaptive Cruise Control (ACC). The controls are commonly positioned to the left of the driver and on the steering wheel. The displays are positioned on the instrument cluster displays in front of the driver. The requirements to these displays concern the signs and the text shown on the display and the human informational processes. The IVIS allocate functions and parameters not belonging to the main driving functions, like the sound system, telephone functions or chassis suspension adjustments, to the right of the driver.

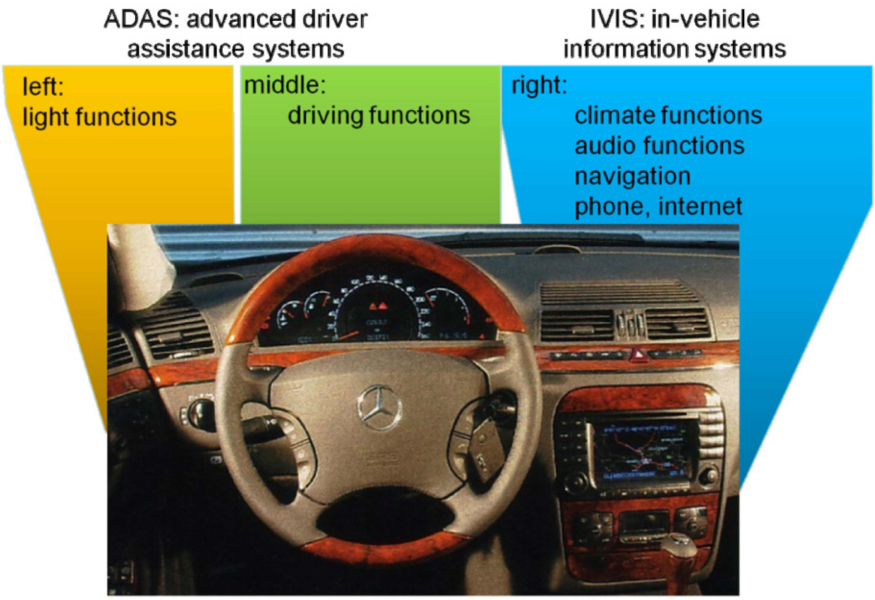

Fig. 36.8: The cockpit of a modern car

3.3 Ergonomic Design Rules

Several design rules concerning the ergonomic design for the interior design have been developed. Historically grown conventions, as well as scientific knowledge, have to be taken into consideration. The three main rules are described below.

3.3.1 Compatibility

The growing requirements of modern traffic make it necessary that the driver perceives all the information he or she needs and reacts in the right way. The complexity to transform the information has to be as low as possible. To reach this goal, the compatibility has to be considered. Compatibility concerns the interdependence of displays, controls and the outside world.

Primary compatibility describes simple relations between the use of controls and the effects on a system, e.g. moving a lever to the right means to move an object to the right. This can influence the consistency with inner models (internal compatibility) or with the human-machine-interfaces (external compatibility). The aspects of the primary compatibility are nowadays mostly designed in an acceptable or good way.

The secondary compatibility refers to the correct relation between different types of primary compatibilities. The moving directions “up” and “right” should always mean “more”, a certain combination of indicating directions leads to contradicting information (Fig. 36.9). But when using segment displays, design aspects often overrule ergonomic aspects.

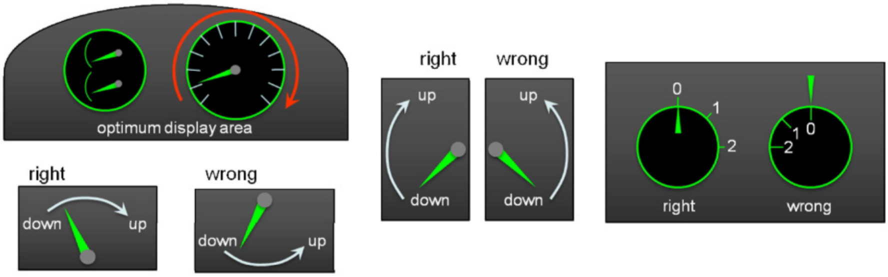

Fig. 36.9: Secondary compatibility in automotive displays

Other issues demand the use of associations (conceptual compatibility), e.g. that “green” means “go”. These associations have to be learned and can differ between different cultures.

3.3.2 Grouping

The design rule of grouping is related to the compatibility rules. Referring to inner models, groups of elements (displays, actuators etc.) belonging to functional entities or subsystems should be arranged in an order that shows their relation (BULLINGER 1994). Accordingly, elements that do not belong together should not be arranged in an order that implies a connection. The Gestalt psychology from the early 20th century has found many laws which describe the influence of object grouping on their perception. For example, the law of proximity states that the mind groups similar elements together (Fig. 36.10). Reasons for this similarity can be some common aspect of form, colour, size, or brightness.

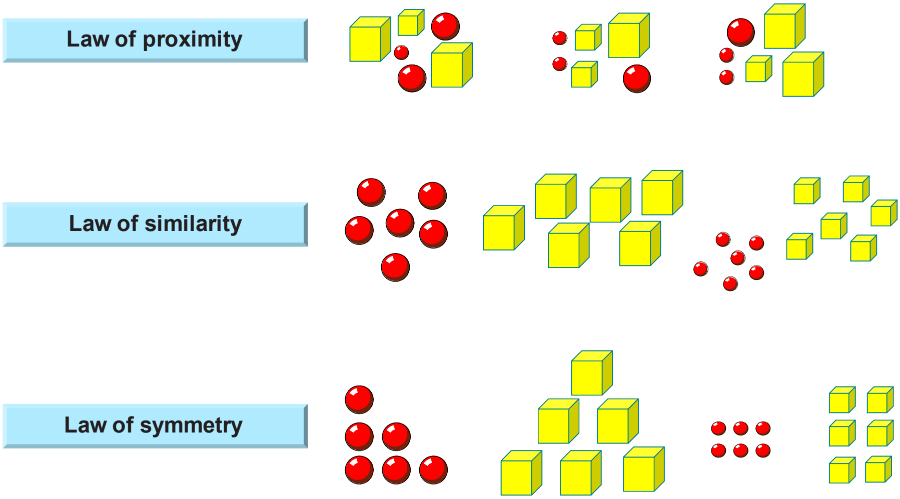

Fig. 36.10: Laws of the Gestalt psychology

3.3.3 Encoding

Encoding is becoming increasingly important due to the growing number of in-car signals and systems. The encoding can be related to the combination of controls and displays or to the meaning of a signal. The first issue should be to design the controls and displays in a way that the driver is able to relate one to the other. The shape, the colour or the material can support this connection.

In the past it was sufficient to inform the driver with a coloured light or a simple sinusoidal sound. Nowadays, the visual signals have to be designed clearly, understood fast and learned easily. The auditory and haptic signals also have to be understood without the use of an additional display. Human information handling has limits and the ADAS and IVIS have to be as simple as possible. Symbols, text, shape, colour, and material can be used to encode information ergonomically.

4 General Aspects in Ergonomics

In the following sections, some general developments in the field of ergonomics are described.

4.1 Digital Human Models

To be able to better design car exteriors and interiors, the possibilities of modern information technology have been adopted in the field of ergonomics through digital human models like RAMSIS. Whereas before the 1990s, ergonomists used small models or stencils of prototypical human bodies to evaluate their designs on paper, this is nowadays done with a three-dimensional model of the human body in a virtual environment (Fig. 36.11). As it is obvious that not all people are alike, these models can be adapted to different anthropometric proportions of the population or even to different nations. These models are then integrated in modern CAD applications and thus enable the designers to evaluate the anthropometric fitness of designs already during early design stages.

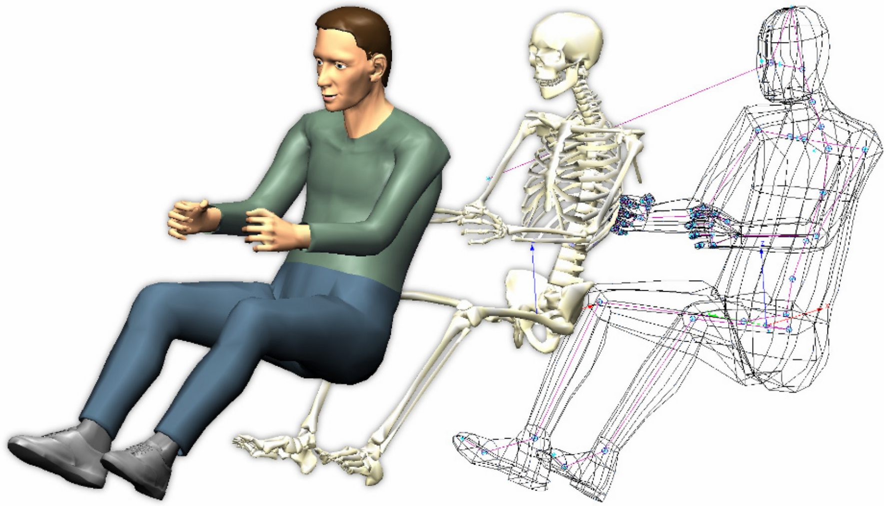

Fig. 36.11: Examples of RAMSIS

4.2 Interculturalism

Many scientific studies indicate that there are profound differences in the ways that people from western and eastern cultures interact with their environment and in the ways they think. Many of these differences are relevant for designing HMIs for different cultures (LEIBER et al. 2008). The most obvious difference is language. Similarly, there are obvious differences in graphics and icons, text and data formatting (e.g. text direction, dates and times), and the meaning of colours. Less observable are differences in perception and cognition. One of the most prominent, even though not undisputed works in this domain is HOFSTEDE and HOFSTEDE (2005). It ascribes cultural differences to differences in five cultural variables, namely power distance, collectivism/individualism, femininity/masculinity, uncertainty avoidance and long term/short term orientation. Of a more fundamental order are the results of various studies presented in NISBETT (2004): He found strong differences between Easterners and Westerners in object recognition, in the role of situational constraints, in object categorization, and in the application of logic reasoning. The area with the least knowledge is the difference between cultures in the perception of esthetics, although it is obvious to everybody who has travelled to other countries that such differences exist.

Research shows that culturally adapted human-machine interfaces have advantages over global user interfaces, e.g. they lead to a reduced number of errors and to higher customer satisfaction.

4.3 Demographic Issues in Ergonomics and Design

The demographic change is progressively influencing the product development and production planning. In almost all industrial nations the individuals are getting older and the average age is rising. For example in Germany by the year 2050, the number of people over 65 years old will equal to the number of people who are aged under 20 years. The average age of Europeans will increase from 39 years in 2004 to 49.5 years in 2050. The elderly have a high buying power and have higher demands on comfort and usability. These effects cause designers to deal with the special needs and abilities of the elderly. To consider these aspects, the designers – who are often younger – have to apply the knowledge about age-related changes in their development and planning processes. An age suit like the Age Simulation Suit, developed in cooperation of the Professorship of Human Factors and Ergonomics at the Chemnitz University of Technology, AutoUni, AUDI AG, and Volkswagen Forschung (Fig. 36.12), gives the possibility to experience those differences even to younger persons.

Fig. 36.12: The Chemnitz MAX, an age suit to experience effects of the elderly

With an age suit, the designer, ergonomist or planner can experience the usage of products under circumstances that resemble those of elderly people. Tests with the age suit showed that age-driven physical and sensual changes can only be simulated to certain limits, but that experiencing these changes on hand with the age suit greatly improves the knowledge about aging-related needs concerning products and processes.

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37 Design of Visual and Auditory Human-Machine Interfaces with User Participation and Knowledge Support

Gunnar Johannsen

1 Introduction

Human-machine interfaces for dynamic technical systems (such as industrial processes, vehicles, etc.) are a particularly important and complex subset of user interfaces. The design of these interfaces has become so sophisticated that it can, already for quite some time, no longer be handled in an intuitive fashion. The designer needs to possess a huge amount of multidisciplinary knowledge and experience with respect to the application domain of the respective technical process, the available automation and information technologies, the capabilities and limitations of the human users (human operators, maintenance personnel, and others), work psychological and organizational matters as well as ergonomic and cognitive engineering principles of good human-machine interface design.

Participative design is mandatory for achieving better human-machine interface products. This is a strong human factor concern that still needs to be implemented more often and more systematically in industrial design projects. In addition to a systematic design approach with user participation, different forms of knowledge support are appropriate means for achieving good design solutions.

This article outlines the functionalities of human-machine interfaces (Sect. 2), describes systematic design stages with user participation (Sect. 3), explains possibilities of knowledge-based design support (Sect. 4), and exemplifies designs of visual and auditory displays (Sect. 5). Thereby, the paper summarizes several contributions from earlier publications of this author (JOHANNSEN 1994, 1995, 1997a,b, 1999, 2000, JOHANNSEN et al. 1995, 1997a,b). More references can be found in these cited publications.

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2 Functionalities of Human-Machine Interfaces

Any human-machine interface is installed between one or several human users and a dynamic technical system (the so-called machine, i.e., the application) which includes the dynamic technical process and its automation and support systems (JOHANNSEN 1992). The functions specification for the human-machine interfaces depends on the goals and the goal structures prescribed for the human-machine system, on all kinds of technological and intellectual means for accomplishing these goals, and on the tasks to be performed by the human users with the purpose of achieving the goals by appropriate usage of the available means.

The overall goals of the human-machine system are mainly (1) productivity goals, (2) safety goals, (3) humanization goals, and (4) environmental compatibility goals. An appropriate goal structure needs to be specified in which these four goal classes are related to each other and further subdivided into several hierarchical levels of sub-goals. The productivity goals include economic as well as product and production quality goals. The importance of the safety goals is strongly influenced by the application domain. This goal class dominates all others in many large scale systems and, particularly, in risky systems. The humanization goals comprise team and work organization, job satisfaction, ergonomic compatibility, and cognitive compatibility. The latter includes the sub-goals of transparency and human understanding. The environmental compatibility goals refer to the consumption of energy and material resources as well as to impacts on soil, water, and air.

The means for achieving the goals can be separated into purely technological means and human-related means. Most issues concerned with the design of the technical process itself are purely technological means. The degree of automation also belongs to this category but represents human-related means, too. The supervision and control systems and, even more, the knowledge-based decision support systems should be designed with a human-centered approach considering human-related means.

The human-related means comprise several issues. Knowledge about the application domain as well as about human users' needs and strategies can be regarded as human-related means. This may be described by structural, functional, causal, and cognitive relationships. Other human-related means are available through different views on the application domain. These views consider the levels of abstraction, the levels of aggregation or detail, parallel versus serial presentation, navigational possibilities, and degrees of coherence. All these means are implicitly inherent in the application domain but often need to be transformed for explicit usage.

The tasks to be performed by the human users depend on certain scenarios, i.e., situations and contexts of the human-machine system. Different experience and knowledge of the human users, as well as different normal and abnormal situations and states of the dynamic technical system, lead to different subjectively perceived tasks. Further, the prescribed goals and the available means for their achievement strongly determine the types of tasks to be performed in a certain scenario.

The functions of any human-machine interface (HMI) should be defined in such a way that the prescribed goals can be achieved, the available means can be transformed and used appropriately, and the tasks can be correctly perceived and effectively performed. The HMI functions can be specified into the following global categories:

- supporting the accomplishment of all goal classes (goal functionality),
- supporting the transformation and usage of all available means (means functionality),
- supporting appropriate task perception and performance (task functionality),
- organizing sufficient and timely information transfer from and to the technical system and all its subsystems with respect to goals, means, and tasks (dialogue functionality),
- visualizing all process and systems states with respect to goals, means, and tasks (presentation functionality),
- supporting the compatibility and the adaptability of the human-machine interaction to the human users (user functionality),
- supporting the human understanding by providing adequate explanation and justification (explanation functionality), and
- avoiding or compensating for human errors (human error-tolerance functionality).

The more traditional levels of human-machine interfaces, such as presentation and dialogue, are separated from each other under the UIMS perspective (User Interface Management System); see e.g., JOHANNSEN (1992). The dialogue level deals with the information flows regarding such problems as what information to handle at what time. The presentation level is concerned with the problems of how to present the information to the human users, and how to transform their control inputs. The human-machine interface includes the functionalities of Handling Inputs and Generating Outputs, which are both typical presentation level functionalities. The Generating Outputs functionality normally contains a lot of graphical and textual dynamic pictures and is designed by means of special graphical editors. The knowledge contained in the Generating Outputs functionality is represented in graphical objects and in related non-graphical information about the technical system (FEJES et al. 1993). The main mode of presentation is still the visualization created with the dynamic graphical editors. However, multimedia interfaces with speech output (STREETER 1988) and other auditory information are, in addition, increasingly important (JOHANNSEN 2004).

The dialogue functionality, also called Supervising Dialogue, can be designed as a quite complicated goal-oriented component for handling the dialogue between the human user(s) and all other components and subcomponents of the human-machine interface and, thereby, of the technical system (ALTY & JOHANNSEN 1989). Among other subfunctionalities, this includes the resolution of possible conflicts between different components with respect to dialogue requests to and from the human user(s). Another human-machine interface functionality deals with Tracking Interaction, i.e., the complete interaction between the human-machine interface and both of its sides, namely the human users and the machine. Knowledge-based sub-functionalities of Tracking Interaction are responsible for updating the interaction context and for quality control of the whole human-machine interaction.

Both the presentation and the dialogue levels can explicitly depend, in their functionalities, on the goals as well as on technical systems or application models, and on user or operator models. The more explicit representation of such models in the human-machine interface leads to more advanced paradigms (JOHANNSEN & AVERBUKH 1993). A Technical Systems Model contains the knowledge about the goals, the structure and the functions of a particular application. The functionality of the technical systems model internally supports all the other functionalities of the human-machine interface. Frame, rule, and causal network representations can be used for building such a model. Dependent on the intended dynamicity, such knowledge representations may not be sufficient. A combination with proven theories and methodologies implemented with numerical algorithms often seems to be more appropriate. A user model functionality is needed if a certain adaptability to human user classes or single users shall be achieved (KOBSA & WAHLSTER 1989, SUNDSTRÖM 1991). A more elaborated user model will always include a technical systems model in order to represent the user's view with respect to the technical system. In addition, knowledge on human information processing behavior and cognitive strategies has to be represented in a user model by means of algorithms, rules, and, possibly, active inference mechanisms.

3 Design Stages and User Participation

Design processes in general and for human-machine interfaces in particular require a lot of human creativity and flexibility (ROUSE 1986). The design process itself can be viewed as a problem-solving activity. Designers have to be generalists and several different specialists in one person. Therefore, it is not surprising that most designers rely more heavily on their thorough technological rather than on human-related and ergonomic knowledge (MEISTER 1987). The human-machine interface designers should be specialists in the latter but many of them are not. Further, the design style may be individually different, and opportunistic departures from hierarchically structured design plans are very typical with some designers (VISSER 1990).

In order to better adapt human-machine interfaces to operational needs, it is necessary to take the knowledge of utilization from human end-users into account during the design process, and not only the knowledge of functioning in which the engineers are more interested (DE MONTMOLLIN & DE KEYSER 1986). One way to do this is the participative design approach. Hereby, human users are involved in many of the design stages from the very early beginning of the development/design life cycle on (JOHANNSEN et al. 1995). Special participative rapid prototyping tools are necessary in order to optimize the design in a co-operative way between designer and human user. The human user has the opportunity to concentrate on his or her application knowledge without the need to become knowledgeable about software and interactive computers.

The objectives of user participation reveal a surprising multitude of aspects. Most of these aspects depend on the viewpoint, e.g., whether they are judged by the management or the end-users or even by the designers. The different types of objectives are briefly listed.

- Management Perspective: The management is supposedly mostly interested in meeting the productivity and safety goals. Participation of users helps to develop interfaces that are much more appropriate to the task requirements, thus providing a more efficient and secure way to handle a given technical process.
- End-Users Perspective: Involving the users into the design process can be seen as part of a tendency to increase the overall capabilities and also responsibilities of the end-users. It also helps to mediate a feeling of “being asked”, e.g., of being able to exert an influence on the whole working environment. Besides the fact that the interfaces will be more convenient, taking a user seriously will also improve the overall task orientation and, thus, the commitment to the work.
- Designers Perspective: The designer works more application oriented and with a greater certainty about later user acceptance when he or she considers the participation of end-users as an integral element of any good HMI design. This is particularly demanding for multi-human machine interfaces because several different human users have to be consulted during the participation process.

Any user-oriented design of interactive software products, such as human-machine interfaces, should start with definitions of user classes, overall goals and means for their achievement. In addition, task analyses are also necessary in order to have a solid basis for user requirements and systems specifications, particularly for the functional specifications of the human-machine interfaces. User requirements should consider the goals-means-tasks relationships and should be based on a task-oriented perspective.

Methodologies have been developed that allow the support of designers of human-machine interfaces in their design and evaluation activities. The objectives are to enhance the efficiency of these activities and to improve the final interface products. The methodologies combine systems engineering life-cycle procedures with end-user participation and rapid prototyping. One of these methodologies is the Graphical User Interface Design and Evaluation method GUIDE by REDMOND-PYLE and MOORE (1995). Strictly speaking, it is restricted to human-computer interaction, i.e., systems without dynamic technical processes. However, many of the GUIDE techniques are also relevant for dynamic systems. Further, this design method strongly emphasizes the presentational issues, yet also includes the dialogue issues.

The design stages of the GUIDE methodology have specific objectives and deliver well-defined outputs. The methodology starts with defining user classes and usability requirements (see Fig. 37.1). Then, task models and task scenarios are produced. The user object model is specified by the designer with the intention to support the development of an interface in which such a user object model may create effective mental models inside the users' mind. Presentational issues and also navigational/dialogue issues are considered by the style guide, which needs to contain particular guidelines for visual and/or auditory presentation. The stage of designing the HMI, in the narrower sense, is based on all these specifications. It refers to the initial design of the interface and should provide a solid basis for prototyping. Several iterations lead to progressively improved versions of prototypes via respective intervening evaluations and usability testing (see Fig. 37.1).

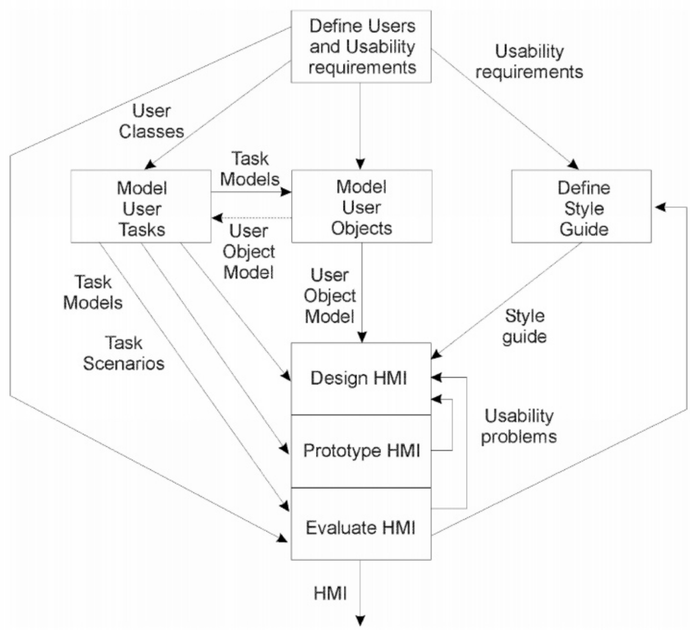

Fig. 37.1: Cognitive systems life-cycle development of HMI (Human-Machine Interface) displays (after REDMOND-PYLE & MOORE 1995)

4 Knowledge-Based Design Support

The designer of human-machine interfaces can be supported by knowledge modules. The example of Fig. 37.2 presents six knowledge modules, namely (1) the Goals knowledge module, (2) the Application knowledge module, (3) the Users knowledge module, (4) the Tasks knowledge module, (5) the Human-Machine Interface (HMI) knowledge module, and (6) the Design Procedures knowledge module. These modules should not be viewed as only separate support subsystems, but also as interrelated knowledge pools.

The Goals knowledge module contains information about operational design criteria with respect to efficiency and performance, safety, reliability, producibility, costs, development time, etc. Several goals-means relationships from the research literature as well as from industrial experience can be included in this module.

The Application knowledge module comprises knowledge about the technical process and its supervision and control (S&C) system, as well as about the knowledge-based decision support systems (DSS) of the technical system. All this structural and functional knowledge can possibly be loaded from plant and control systems data bases as well as from the knowledge bases of the decision support systems. Thus, the technological knowledge of the application domain is made available to the interface designer in a consistent form.

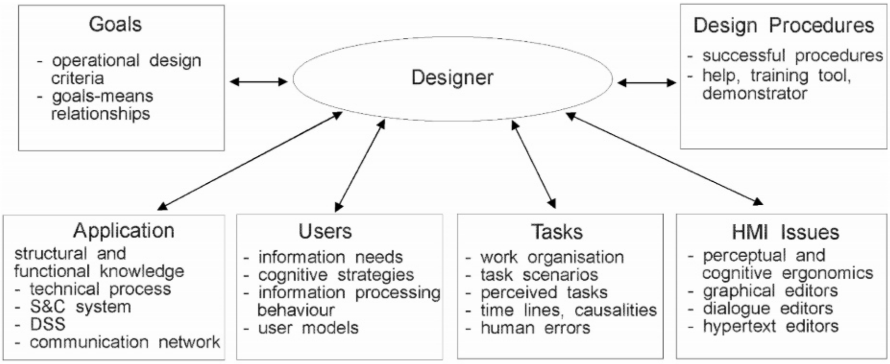

Fig. 37.2: Knowledge modules for supporting the designer of human-machine interfaces (from JOHANNSEN 1997a)

In a corresponding way, the Users knowledge module supplies the designer with knowledge about the information needs, the cognitive strategies, and the information processing behavior of human users. Such users' knowledge is more difficult to collect than the application knowledge. However, the combination of cognitive task analyses with knowledge-based user modeling provides a way in which real human-centered designs of human-machine interfaces are possible.

The Tasks knowledge module considers the work organization, the task scenarios, and the perceived tasks. The knowledge of this module interlinks the knowledge of the two preceding ones. Typical task scenarios may be described as time lines and causalities of events. Further, a task-related categorization of human errors will support the designer in her or his decisions.

The Human-Machine Interface knowledge module (HMI Issues) works on the basis of the other modules that have just been described. This module is the most active part of the knowledge-based designer support and contains several editors for the presentation, the dialogue and the hypertext levels, as well as related knowledge about perceptual and cognitive ergonomics. The levels of presentation and dialogue are linked with each other through object hierarchies. The editors for the presentation level are mainly graphical editors (FEJES et al. 1993). They allow one to design different picture pyramids for different abstraction levels, different window layouts, different information forms (e.g., flow diagrams, functional diagrams, textual messages, analogue and digital instruments) as well as all kinds of graphical symbols and other basic elements. The editors for the dialogue level are dialogue specification tools for designing information flow and state transition networks, as well as knowledge-based dialogue assistants. The latter may be oriented towards subsystems or subtasks. Additional editors may be available for creating hypertext structures as well as other data and knowledge bases.

The Design Procedures knowledge module comprises knowledge about successful procedures used by experienced designers. Information about possible design failures and about how to avoid or correct them may also be included because designers can learn not only from successful experience, but also from a failure. This module can serve as an aid, help or reminder to the design experts as well as a training tool or a demonstrator for design novices.

5 Designs of Visual and Auditory Displays

5.1 Visual Displays

In conventional human-machine interfaces, the visualization of dynamic processes is mostly realized by the use of topological representations. These kinds of user interfaces become very intricate when the functioning of complex plants has to be visualized. JOHANNSEN et al. (1997a) provided solutions to this problem with a Multimodel-Based user interface approach, as well as with a Goal-Oriented Functional display approach.

With the Multimodel-Based user display approach, an interface is designed on the basis of a set of models that represents the process (and the whole technical system) on different levels of abstraction and from different viewpoints. This set forms the so-called multimodel. A multimodel is acquired through task- and process-analyses and includes elements that contain knowledge about process variables, states, process goals, security classes, strategies, economic efficiency, etc. All these elements are based on the experience and the knowledge of human users (particularly, of operators) and are stored as objects in the knowledge base of the human-machine system.

Great emphasis is put on the integration of the different models within the knowledge base to achieve a consistent visualization of the dynamic process (and the whole technical system) on the user display. The knowledge about the technical system is acquired in collaboration with experienced users and expressed in natural language. Fuzzy logic is used for translating these natural language procedures into objects in the knowledge base of the human-machine system and, also, for the visualization of this knowledge on the user display.

The multimodel contains the following models:

- A model of the human information processes involving human decision making. This model is not explicitly used in the design of the user interfaces, but it is applied in the design philosophy.
- A model of the psychological task levels of operators. This model describes different psychological task levels that cover the whole spectrum between the technical process and the actions of the human operator. For all subprocesses, state-critical subsystems in the technical process can be distinguished.
- A qualitative states-causal model. This model contains objects that describe the critical subsystems. Such subsystems have a qualitative state. These are states of the process as perceived by experienced operators (e.g., the states are “optimal”, “high”, etc.).

The Goal-Oriented Functional display approach has been based on the integration of interfaces designed with two techniques, namely the Multilevel Flow Modeling (MFM), developed by LIND (1990), and the Ecological Interface Design (EID) by VICENTE and RASMUSSEN (1990). These interfaces integrate the knowledge about the plant into the display. Further details are discussed in the book chapter by JOHANNSEN et al. (1997a).

5.2 Auditory Displays

The design of auditory displays has been investigated by JOHANNSEN (2000, 2004) over several years. A mobile robot in a supermarket scenario characterizes the example application domain. The directional orientation and the intent communication of the robot have been indicated to the human by means of auditory displays. Two user classes are considered, namely non-musicians and musicians. The usability requirements include understandability and recallability of auditory sounds. Two successive task scenarios deal with the directional orientation in an abstract open space with eight possible directions and, then, with the communication of robot trajectories and states in a fixed supermarket floor plan. Important user objects are directions as well as additional states such as Heavy Load and Near Obstacle.

The development of style guides for auditory displays requires major efforts, mainly on the levels of research, sound design, classification and standardization. For the work with the mobile robot in a supermarket scenario, a heuristic approach based on knowledge from music theory and sound engineering was chosen. The systems life-cycle phases of design and prototyping include the design of directional sounds and robot sound tracks. This was accomplished with basic musical elements and recorded robot noise signals. The robot sound tracks actually used in the experiments of the supermarket scenario were the overlapping of the sound tracks of the intended robot trajectories and, during some of their segments, the additional sounds for the robot states and situations Heavy Load, Waiting, Near Obstacle, and Low Battery. In the second half of the experiments, the sounds of the real robot movements were also overlaid. The experimental investigation with user evaluations and usability testing showed that the sound symbols and the sound tracks are recallable and understandable, at least for more musical people. Positive training effects were observed with all human subjects. The investigated digital-audio sound tracks are feasible means of communication in human-machine interaction. Further research needs to also consider other application domains.

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38 Human-Computer Interaction in Aerial Surveillance Tasks

Ludger Schmidt, Daniel Ley

1 Introduction

Supervisory control of complex systems or processes by a human operator can be understood as a superordinated control loop of the technical system. In this procedure there are three steps: (1) the operator monitors the state of a process or system, (2) he analyses and assesses it in comparison with a desired state, and finally (3), a correction by a specific operation is planned and carried out, if necessary. In the context of military aerial surveillance, the essential identification and classification tasks of aircrafts are based on various sensors and data exchange with other military units. Numerous additional conditions (e.g. the political situation) have to be considered. To assist operators in aerial surveillance tasks as well as in time-critical situations and at a computer workstation with a high informational workload, the design of ergonomic human-computer interaction is a crucial factor.

A model-based design of human-computer interaction for aerial surveillance tasks at military workplaces is described in this contribution. First, interactions are generally characterized according to an extended semiotic model containing four levels of interaction (pragmatic, semantic, syntactic, and physical). In the second step, the model is used for deriving and describing design consequences. Finally, as an example, it is illustrated how to design a user interface for aerial surveillance tasks according to the model.

2 Semiotic Model for Interaction Design

There are established qualitative models for cognitive and operational processes for systematic analysis and design of human-computer interaction in supervisory control tasks, which distinguish different levels of interaction (e.g. NORMAN 1986,

C.M. Schlick (ed.), *Industrial Engineering and Ergonomics*,
DOI 10.1007/978-3-642-01293-8_38, © Springer-Verlag Berlin Heidelberg 2009

RASMUSSEN 1986, KLEIN 1993, RASMUSSEN et al. 1994, SHERIDAN 2002, SCHMIDT & LUCZAK 2006a). Human behavior evolution aims at and is specialized in interpersonal communication and interaction. Hence, in accordance with cognitive ergonomics, well-founded interpersonal communication models should be transferred to human-computer interaction. An intuitive interaction analogous to highly trained human-human-communication patterns can be of fundamental importance, particularly at security-sensitive systems that are characterized by unscheduled events, time-critical decisions and interventions as well as by serious consequences in case of human errors.

Similar to interpersonal communication, human-computer interaction covers "digital" as well as "analogue" parts. Digital parts are communicated with words, or more specifically symbols, and are mostly unambiguous. In contrast, analogue parts can be interpreted freely, so they need to be disambiguated (WATZLAWICK et al. 1967 for a definition of the parts). Facial expressions are an example of an analogue medium with regard to human-human communication. The use of complex symbols and metaphors is an analogous example for human-computer communication.

The approach taking advantage of interpersonal communication for the design of human-computer communication differs from technology-centered interaction-models. Although these forms of communication initially appear to be quite different, it seems reasonable in human-computer interaction to make use of the extensive existing knowledge of interpersonal communication because of the equivalence described above (q. v. LUCZAK et al. 2003). This consideration is confirmed by the distinction of different levels of communication by the semiotic model, which transcend simple information as well as communications engineering models.

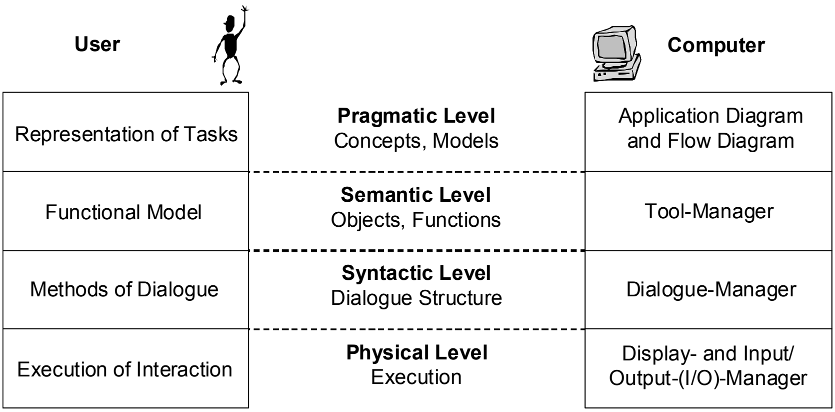

Fig. 38.1: Semiotic model, describing the four levels of human-computer-interaction

Originating in linguistics, MORRIS (1946) describes three levels of communication processes with regard to the semiotic model: (1) formal relations between signs on the syntactic level, (2) relations between signs and described objects on the semantic level, and (3) references between signs and their users on the pragmatic level. Analogously, human-computer interaction can also be considered as transmission of information by the exchange of symbols with specific meanings. As a result, the semiotic model of interaction was also applied to the ergonomic design of human-computer interfaces (FOLEY et al. 1990, ANDERSEN 1997, DE SOUZA 2005, HUGO 2005, LUCZAK et al. 2006a). Additionally, a physical (or lexical) level (0) was introduced that describes the execution part of interactions (see Fig. 38.1). Thus, user interactions can be differentiated into four levels – pragmatic, semantic, syntactic, and physical – and allocated to the corresponding hierarchical level in the technical system.

2.1 Structuring Interaction According to the Semiotic Model

An interaction cycle in this model can be described as follows: a definition of the interaction's purpose and task is made at the topmost level. Based on the user's mental model (SCHMIDT & LUCZAK 2006b), this definition results in concepts and models (pragmatic level). At the next level (semantic), objects are created and modified by choosing the corresponding tool functions. These functions are activated by one or more dialogue steps (syntactic level), which are conducted by one or more physical operations (physical level). The operations are physically registered and syntactically interpreted by the computer. The functions that are thus activated realize the superordinated concepts, while the superordinated models are composed of objects and their relations. Subsequently, the system status changes top-down by computerized task processing. The user receives information about the changes at the physical level and deals with them bottom up, by decoding and interpreting them for a comparison with the desired state.

2.2 Model-Based Design

According to the structure of the semiotic model, a user- and task-oriented design process should include all levels described. Initially, the tasks of the user under consideration are derived from the organizational work context (LUCZAK 1997). In the first step it is clarified if and how these tasks may be supported by a computer. In addition to task sharing, operation contents, application areas, the characteristics of the users or the user group (e.g. skills, abilities, and behavior) have to be taken into account (LUCZAK et al. 2003). The computer-based implementation of the respective concepts and models corresponds to the definition of fundamental procedures as well as the specification of an application model for task completion. The work-related problem and its possible solution are described on the pragmatic level. The three subsequent levels deal with the interaction problems associated with the computer-based solution for the work-related problem.

The modality of software-based processing a subtask depends on the following conditions: the functions to be determined on the semantic level, and the models represented on the pragmatic level for task solving, substantiated here by the structure of objects and their relations. The kind of object structure that can be created and manipulated by the software essentially defines the possibilities of processing the tasks. In combination with the functionality of the software they influence the activity of the user or rather the task-sharing between human and computer (semantic aspect). Hence, on the semantic level of the computer system, i.e., functions are defined for activities that have not thus far been computer-aided (i.e., to conform to user expectations). An understanding of the effects of functions needs to be developed to support self-descriptiveness. Also, reversibility (in case of incorrect execution) has to be implemented (error tolerance) and choices have to be offered between different functions (controllability).

On the syntactic level it needs to be determined how a given function can be activated for execution. For this purpose, syntactically declared commands are stored in a dialogue structure (e.g., a selection from a menu or an entry as sequence of key strokes). The seven dialogue principles defined in ISO 9241-110 (2006), – suitability for the task, self-descriptiveness, controllability, conformity with user expectations, error tolerance, suitability for individualization, and suitability for learning – can offer an orientation for the ergonomic design of dialogues between a user and an interactive system. Conformity with user expectations would mean, for example, the consistent indication of parameters and the continuous use of standard elements such as radio buttons, checkboxes, etc. Controllability may be supported by the choice between menu prompting and keyboard command entry. The naming of short cuts of the menu items could be helpful for learning. By a direct manipulation of objects, the criteria of self-descriptiveness would be fulfilled, which means that all objects of interest should be apparent and operations should take place directly on the objects.

The physical level concerns exclusively the real interaction between human and computer: On the one hand, activities for the entry of information have to be designed on this level (e.g., motion of the computer mouse, pressing of a key, voice entry). On the other hand, at the information output of the computer, the following issues have to be considered: perceptibility of characters, complex symbols and graphic elements (e.g., form, dimension, brightness, color, contrast, refresh rate), presentation and arrangement of data (e.g., grouping of information belonging together, minimization of selection movements in menus), and encoding of information (e.g., font, graphic, language). Also the arrangement of the workstation (e.g., table, chair, devices) and the design of the work environment (e.g., illumination, climate, noise, and radiation) belong to the execution level for the input and output of data. At this level for standardized workstations it is possible to take advantage of ergonomic findings (LUCZAK et al.

2006b), which expand into the corresponding standards to a large extent (e.g., parts 3–9 of the above-mentioned ISO 9241).

3 Example Application to Air Situation Assessment

Below, naval air situation assessment is the basis for an example application for the design of human-computer interaction based on the semiotic model. For the processing of the corresponding tasks a multitude of data are received in the combat information centre of the own ship by means of active and passive sensors as well as a network of sensors (LINK). These data have to be visualized in such a way that the corresponding operator is able to develop a complete and unambiguous situation picture in an appropriate time-frame, evaluate the situation and finally derive actions, if necessary. In these complex workflows the identification and classification of aircrafts is an essential work step. But even when using a decision support system the operator holds the final responsibility. The operator needs and processes information about the geographical situation (e.g., the location of airports, airways, seaways, military areas and passages), the political situation (e.g., friendly, hostile and neutral parties), the tactical situation (e.g., strength and form of military forces) and the current rules of engagement (e.g., general behavioral rules, but also concrete identification directives). This information is used for the interpretation of the control system data concerning the characteristics and movements of the aircrafts (tracks).

The separate design levels of the semiotic model were taken into account in the prototype design described below, which was developed in cooperation with naval experts for the area of aerial surveillance on German navy frigates (GRANDT et al. 2005, GRANDT & LEY 2008).

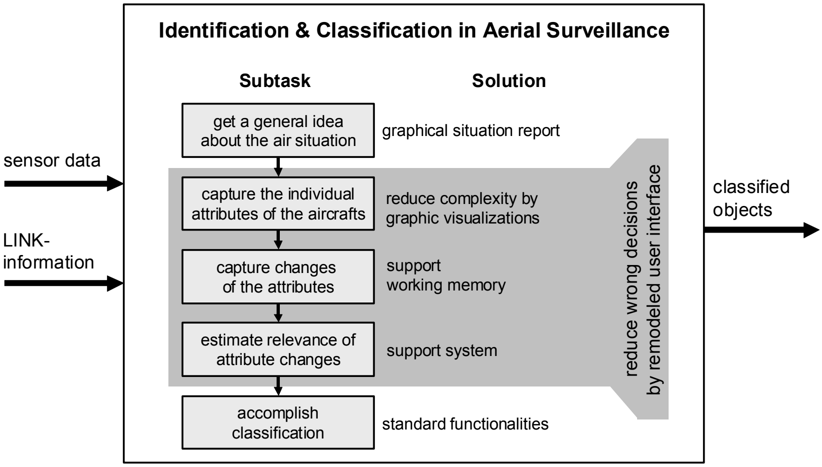

Fig. 38.2: Concept for the prototype design for air situation assessment

3.1 Pragmatic Level

Figure 38.2 illustrates the concept of the prototype that has to be designed on the pragmatic level and is based on an analysis of the user's tasks.

First, the operator needs a general idea about the air situation. For this purpose he will be provided with a graphical situation report in the form of an artificial radar screen (refer to 6 in Fig. 38.3). Subsequently, he has to capture the individual attributes of the aircrafts (such as altitude, course, electro-magnetic radiation). The operator needs to be supported by graphic visualizations of the originally alpha-numerical information which are easier to detect and capture.

In case of changing attributes, the operator's working memory gets supported by describing information regarding the past. A rule-based support system offers plausible possibilities for the classification of aircrafts in order to support the operator by estimating of relevance of attribute changes. In the final step, the input for the command system is implemented by conventional standard functionalities. The required inputs are sensor data and LINK-information, the outputs are classified tracks.

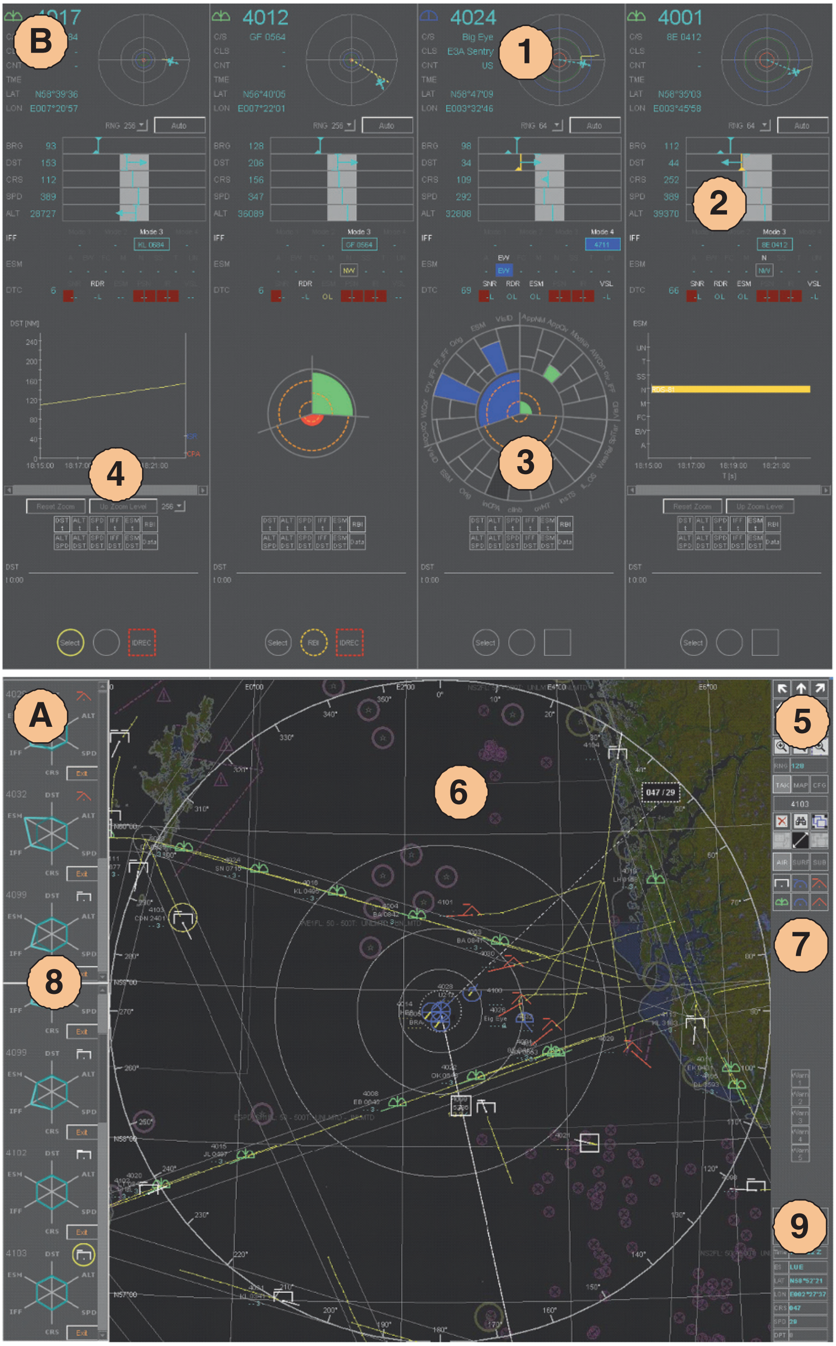

Fig. 38.3: Prototypical user interface for the workstation of an operator in aerial surveillance

3.2 Semantic Level

The specification of the idea developed on the pragmatic level is the focus of the semantic level. This specification includes the determination of the function allocation between the operator and the system. In this application example it is important to support the operator in processing the tasks and not to automate the sequence of tasks. Furthermore, the operator will have extensive possibilities for handling and full control of all processes and decisions. However, the operator will minimize the utilization of cognitive resources. Hence, previous information will be visualized, such as the flight path or changes of altitude or speed that are relevant for the classification and otherwise could only be reconstructed from memory. An inference system is supposed to submit classification recommendations based on specified rules. For instance, it can recommend a track as a civil aircraft because of its existent airway conform behavior. This can be determined by its position (location inside a defined airway), speed and altitude.

The operator's handling of the system is influenced by the characteristics, structure and functionality of manipulatable objects. Several operators can interpret the effect of these objects differently. Hence, it is an aim to confine this spread of associativity and to use – in terms of self-descriptiveness – preferably meaningful and clear functions and objects. Further, there should be a correlation as strong as possible between the information which has been conveyed and that which has been understood. Therefore, on the one hand the prototype uses standard functions and metaphors that are common in civil areas (7 in Fig. 38.3) (e.g., the symbol of a magnifying glass for zooming); on the other hand, it uses the SATIR-standard symbols and colors known by the marine operators.

3.3 Syntactic Level

On the syntactic level the sequence of a logical dialogue structure must be ensured and the principles of ergonomic dialogue design must be considered. For instance, possible sequences which are realized in the prototype mainly use the dialogue technique of direct manipulation, so that transparency is assured: tracks can be selected manually on the radar screen and their conditions can be changed by operations which are made available in appropriate lists. Particularly this is applicable to the track-related allocation of classes: In a first step the track to be classified must be selected on the radar screen by a mouse click, whereby object-related information is switched visibly for analysis automatically. Subsequently, the favored class can be selected out of a toolbar; thereby the display of the track is adapted automatically.

Afterwards, according to the selected class symbol, the list is extended with several symbols of subclasses. Thus, a subclass can optionally be assigned if specific information about the object is available. Across all dialogue structures the chronological reasoned sequence is considered and the suitability for learning is supported by tooltips. Additionally, there is more clarity by unchangeable window sizes and positions to prevent disorientation. Further considered criteria are the conformity with user expectations by securing consistent designation of parameters across the entire user interface and the controllability of the dialogue by using an individually selectable speed of dialogue.

3.4 Physical Level

In combat information centers the choice of and spatial arrangement of information input and output units and all further specified environmental factors could not be influenced. Hence, on the physical level only the coding of information as well as the structure of the displays was dealt with.

In addition to the guarantee of perceptibility of elements by the use of high-contrast displays with an adequate size, a central aspect is the coding of information by a graphic visualization of information which is conventionally only displayed alphanumerically. Thus, polar displays (8 in Fig. 38.3) represent the six most important attributes of each aircraft and show its changes graphically by the refraction of symmetry. On the one hand, information relating to the past can be recalled by different graphs (e.g. (4): distance over time), on the other hand, the previous air route of selected tracks is displayed on a miniature radar (1). Proposals for classifications are presented in evaluation-displays (3), which represent the proposal in an inner circle and the value of attributes – as an explanation component according to this proposal – in an outer circular ring. The areas of the tolerance displays with respect to certain attributes of a track (cf. (2): grey sectors) visualize their target area as well as respective existing values and tendencies of the track.

The arrangement of the different displays is designed in a way that all operations required for the classification of tracks are provided on a primary display (A): radar screen (6), polar displays (8), toolbox (5) as well as information about the own ship (9). More concrete information can be displayed on a secondary screen (B), if necessary.

4 Conclusion and Outlook

As shown with the example of aerial surveillance, hierarchical levels of human-computer interaction can be differentiated and applied to the systematic design based on the semiotic model.

The hierarchical levels can also be used with respect to an evaluation regarding the software-ergonomic criteria. Here, it is postulated that every criterion is fulfilled for any hierarchical level. For this purpose the criteria are operationalized in relation to the levels of the semiotic model. For example, the criterion "suitability for learning" would be fulfilled on the syntactic level by the possibility for the operator to refresh his knowledge. In the naval human-machine interface this is implemented by means of context-sensitive information displays (tooltips). Another example is the availability of different alternatives for the execution of procedures, which is recommended on the semantic level with respect to controllability. For this criterion the prototype described offers the option of graphical or alphanumerical representation of information.

In the context of teamwork of operators in combat information centers of navy frigates, an enhancement of the model to accommodate multiple workplaces is necessary in a future step, in which macro-ergonomic aspects may be taken into consideration.

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Standards

ISO 9241 (2006) Ergonomics of Human System Interaction, Part 110: Dialogue Principles.

39 Implicit Interaction in Multimodal Human-Machine Systems

Matthias Rötting, Thorsten Zander, Sandra Trösterer, Jeronimo Dzaack

1 Introduction

Imagine you click on a file on your computer by mistake. The computer processes the information and starts to open the corresponding application. But this takes some time. You immediately recognize your mistake and prepare to close the application right after it opens to continue your intended task. You feel distracted and helpless and your feelings are accompanied by facial expressions and inner thoughts. How would it be if the technical system could understand your mistake by analyzing selective information of you, the user? Like humans do in face-to-face communication, the system would recognize your mistake almost as soon as you did and adapt accordingly.

This article describes our approach to integrate implicit information into human-machine interaction. In a first step we define the new aspect of implicit interaction and relate it to existing approaches of human-machine interaction. Building on this we introduce in a second step two different ways of interaction with technical systems: (1) gaze-based interaction and (2) brain-computer interaction.

2 Human-Machine Interaction

Human-machine systems are defined as systems that integrate goal-oriented co-operation of human beings and technical systems to fulfill a specific task (TIMPE & KOLREP 2002). Regarding this definition the user has to communicate with the system to execute the given task. To do so the human has to interact with the system using a provided interface. In most of today's human-machine systems this interface requires the user to explicitly state his or her demands and wishes to the technical system (see Fig. 39.1). This implies that once the command is set by the user the technical system starts to process the command. The system is not able to

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detect to what extend an action actually concurs to the users' wishes because the system does not have any means to get a real-time estimation of the situation and the user. To interrupt or end an erroneous action the user can only issue a new command to the system. Current human-machine systems lack the ability to detect implicit information as humans normally do in human face-to-face interaction.

Human-human interaction contains both explicit and implicit information. Humans use both kinds of information to analyze a situation and in this way two-way adaptation of behavior is supported, information is exchanged and the behavior in a group is regulated. In this context we define explicit interaction as a conscious action to exchange information, for example language and script. Implicit interaction can be defined as an unconscious action that is integrated in another action, for example mimic and gesture. Because of the complexity of humans both kinds of information has to be analyzed and interpreted to judge a situation and to choose an adequate action. Implicit interaction helps humans to understand situations and behavior and thereby helps to communicate and cooperate with a wide range of different human beings in an efficient and effective way.

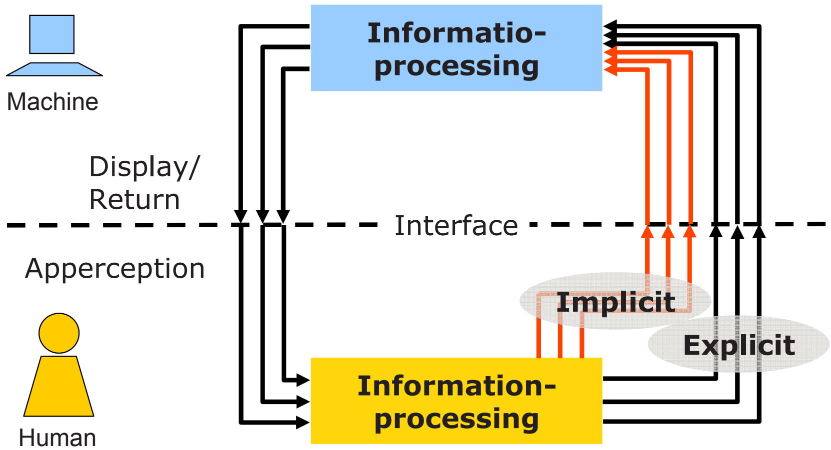

Fig. 39.1: Human-machine interaction enhanced by implicit information

3 Integration of Implicit User Data

We believe that human-machine systems should be enhanced by channels providing the technical system with psycho-physiological and behavioral data of the users (e.g., brain activity, eye movements, peripheral muscles). This would enable the system to access information that is implicitly generated by the human. On the one hand this integrates implicit aspects into human-machine interaction leading to a more human way of interaction. On the other hand this allows technical systems to extend their classical way of directive interaction by the interpretation of the selective implicit aspects. Both aspects can help (1) to meet the expectations of users of how interaction should be designed and how it should take place and (2) to reform the way how technical systems react on external manipulations by humans (e.g., automation, adaption, interpretation).

Two steps have to be taken to allow the computer to assess the implicit user data (see Fig. 39.2). In a first step, the data of the user has to be captured by specific methods and made available to the technical system. In a second step, the technical system has to process the data in four different ways. (1) The data has to be compacted to ensure that only the required information is used for the subsequent steps. (2) The compacted data has to be analyzed regarding cognitive and technical aspects that are connected with the current state of the technical system, its action and, the state of the user. (3) The data has to be interpreted by the technical system. That comprises the assessment of a set of actions that could happen in the future and the assessment of the current action that is processed by the technical system. (4) The last step is the reaction of the technical system in response to the interpretation. The technical system can change a current action or alternatively prepare a new one. The constituted action or plan is performed and in this way presented to the user.

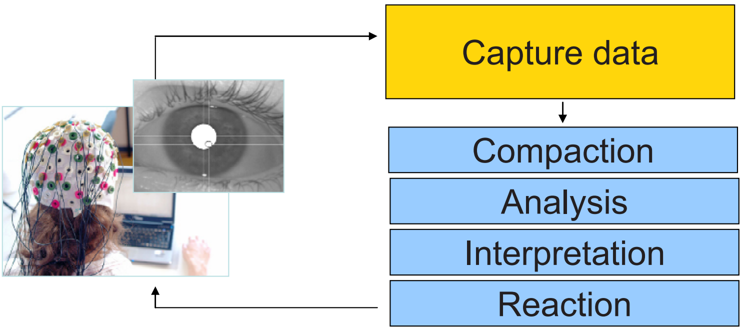

Fig. 39.2: Processing of implicit user data

4 Research Questions

Regarding the example from the introduction, we assume a technical system that is enhanced by mechanisms to access implicit aspects of a user. Following a click on a file, the system detects an increase in the arousal of the user and therefore categorizes the click as a mistake and initiates an alternative action (i.e., the termination of the opening of an application or a question to do so).

Such an approach raises several research questions. One of the most interesting questions is how such a technical system should be designed. Is there a need to report the interpretation and the internal process to the user? If so, how should this be done? Another question is concerned with the selection and combination of implicit channels to provide the necessary information to the technical system and to what degree are these methods accepted by the users. What algorithms can be used to analyze and interpret the data of the user so that the technical system can display a behavior that equals the expected behavior the users know from human face-to-face interaction? And our final challenge is to implement a human-machine system that takes into account several implicit channels and reacts in a way similar to how humans would do.

5 Using Gaze as Interaction Modality

5.1 Introduction

The recording and analysis of eye movements can serve diagnostic and interactive purposes (DUCHOWSKI 2007). For diagnostic purposes objective and quantitative data are used to gain insight into how users process information, to analyze user interfaces or to study human cognitive processing. For interactive purposes, eye data are used as a means of transferring information from a human to a technical system. The use of eye tracking technology is a common approach in helping disabled users to interact with technical systems (HANSEN et al. 2005, MAJARANTA & RÄIHÄ 2002). Typically, for disabled users only information derived from the eye is used for interaction, for example a letter of an on-screen keyboard is looked at and it is selected either by a dwell time measure or an eye blink. For able bodied users such restriction is not necessary and a number of systems have been developed that use, for example, hot keys (e.g., KUMAR 2007), speech (WILCOX et al. 2008) or gestures (RACHOVIDES et al. 2007) to activate a command.

5.2 Implicit Gaze-Based Interaction

Whenever we communicate with other people, our eyes play an important role. We might look consciously or unconsciously at something we talk about. If our eyes stray away, our dialogue partner will not be sure if we actually listen. The expression of our eyes, the size of our pupils, the shine of our eyes are indicators for our dialog partner of how we feel and if what we say is what we mean. In the context of human-machine interaction we use our eyes primarily to locate information within the interface (RÖTTING 2001). In order to use eye movements as implicit interaction instrument, a good understanding of the basic features of eye movements from a psychological point of view is required.

According to JUST and CARPENTER (1980) eye-mind hypothesis, eye movements give information about higher psychological processes (i.e., one fixates the object that is currently processed). Additionally, the duration of a fixation is equivalent to the duration of central processing (immediacy hypothesis). Based on the sequence of fixations, the sequence of central processing steps can be reconstructed. Saccades are the very fast ballistic movements that direct the eye to an object and they can be activated through specific behavior plans or automatically (e.g., through changes in the peripheral field of view). Therefore, saccades and fixations reflect the process of extracting relevant and valid attributes of the external world from sensory information (MARR 1982). This process is generally influenced by top-down and bottom-up mechanisms according to the theory of guided search (WOLFE 1994). WOLFE (1994) assumes that the saliency of an element is influenced by the saliency of the element itself (bottom-up), but also by the task-relevant knowledge (top-down).

The majority of existing gaze-based interaction systems is still designed to replace the computer mouse with gaze information. The location of the mouse cursor is replaced by the coordinates of the current fixation and the mouse click is replaced by fixations longer than a certain threshold (the so called dwell time). So whenever a certain element is fixated for a long enough period, a certain action is carried out. These systems are mostly designed for handicapped users, who can only use their gaze in order to communicate.

How implicit is the gaze-based interaction of such existing systems? Obviously, the degree of implicit gaze-based interaction depends on the application area. For example, when using the gaze to enter text on a screen, this has much to do with intention. The easiest way to enter text using only the gaze is to display a visual keyboard on a computer screen. A normal QUERTY keyboard is shown on the monitor and a letter can be entered by simply fixating it for a short interval. The visual keyboard of ISTANCE et al. (1996) additionally enlarges the part of the keyboard where the fixation is to accommodate inaccuracies of the eye tracker. When using any such system, the user will move the eyes very intentionally to spell the word he or she has in mind. Another system is Dasher (MACKAY & WARD 2002), where the letters of the alphabet are moving from right to left across the screen. A probability-based prediction model is used to enlarge the more probable letters so that they can be selected more easily. The Dasher system assumes to a certain degree what the user wants to write and therefore facilitates the text entry. The information extracted from the gaze is the same in both systems, nevertheless, the Dasher system is designed more implicit than a visual keyboard, because it uses a mathematical model to predict the most likely letter the user will want to type next. Another example for implicit use of eye movements is the iDict system (HYRSKYKARIA 2006). iDict is a gaze-aware reading aid that helps to understand foreign words. The system is based on the assumption that a user fixates an unknown word longer than a known word. The system recognizes the change in fixation duration and then automatically displays a translation proposal.

These examples show that in gaze-based interaction implicit as well as explicit information can be derived from the analysis of eye movements. The examples given so far look primarily at information derived from single fixations. Whenever an object or element is fixated, it can be concluded that it is of certain interest for the user and that it is the current focus of his or her attention. Unfortunately, we can not derive from fixations alone of what kind this interest is, although parameters like fixation frequency or fixation duration provide information about importance, difficulty of extraction, and interpretation of information (JACOB & KARN 2003).

More and different information can be derived from analyzing successions of saccades and fixations, the scanpath. From the scanpath, assumptions about the intention of the observer can be derived. The classic experiments by YARBUS (1967) show that eye movements are strongly influenced by the tasks a subject is instructed to do. KAHNEMANN (1973) refers to this as "task-relevant looking".

The level of workload the user experiences can be judged by the degree of structure of the eye movement behavior and changes in fixation durations. For example, fixation duration shortens with increasing complexity of aircraft (GERATHEWOHL et al. 1978) or car piloting-tasks (UNEMA et al. 1988), and eye movement behavior is more bottom-up influenced when workload is increased (TRÖSTERER & DZAACK 2007).

What does this mean for gaze-based human-machine interaction? If information about eye movement behavior is provided to the machine, it could use this information in order to react or adapt better to the user. Prerequisite is of course that the machine is able to interpret the eye movement data in relation to the elements of the graphical user interface. For example, if an application icon is fixated, the corresponding application could be started in the background, assuming that the interest in the icon will be followed by a click to start the application. If the machine recognizes a special gaze pattern, the intention of the user could be inferred and the appropriate action for that case could be carried out. It might also be possible that the machine proposes help or a break if it recognizes that the eye movements of the user are getting less structured, indicating an increased level of user workload.

6 Enhancing Human-Machine Systems with Secondary Input from Passive Brain-Computer Interfaces

6.1 Introduction

For the development of new implicit information channels between human and machine, accessing the human brain seems to be a very promising approach. Methods from the field of Brain-Computer Interfaces (BCI) based on statistical machine learning have proven to be very successful for achieving this goal. A BCI allows gaining information about the cognitive state of the user without the necessity of the user to produce any activity outside the central nervous system.

The first approach of using brain activity directly for communication comes from Vidal in the early 70s (VIDAL 1973). First steps into the field of application were realized by WOLPAW et al. in the 80s and 90s (2002) by building brain activity-based support systems for patients suffering from amyotrophic lateral sclerosis (ALS).

The application of methods from statistical machine learning (BLANKERTZ et al. 2002) for BCI had a deep impact on the classification accuracy. Subsequently, it was possible to transfer the learning effort from the human being to the machine. Hence, it minimized the effort that is needed to develop the skills to control a BCI system (BLANKERTZ et al. 2007).

When the focus is laid on the applicability of BCI while interacting in typical human-machine system environments we suggest to use the term Brain-Computer Interaction (see Fig. 39.3) instead of Brain-Computer Interface. User states hardly inferable from exogenous factors are estimated by the BCI, interpreted and fed back into the technical part of the system. The information about the user states can be handled as explicit or implicit commands.

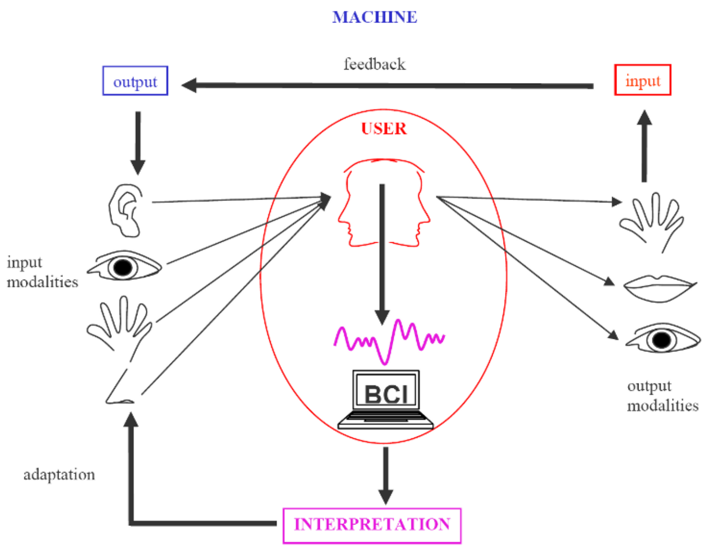

Fig. 39.3: Brain-Computer Interaction – Feedback cycle within a human-machine system augmented by a BCI-based interpretation input

The methods derived from BCI research can be categorized as active and reactive. The term active BCI (aBCI) denotes BCIs which utilize brain activity of direct correlates of intended actions as input. This includes the detection of motor imagery or execution as well as the control over slow cortical potentials (SCP). A reactive BCI (rBCI) is still controlled via intended actions. In contrast to the aBCI, features are not derived from direct correlates to these actions, but from cognitive reactions on exogenous stimuli, as for example in the speller developed by WOLPAW et al. (2002). This speller relies on the identification of the P300 component as reaction to the flashing of the letter that the user wants to type and that the user looks at. In general, the rBCI features seem to be more robust than aBCI features. This might be due to the fact that they usually depend on automatic processes of cognition which are not as easily modulated by conscious processes.

According to this line of thought, a third class of BCIs, passive BCI (pBCI), can be defined (ZANDER et al. 2008, CUTRELL & TAN 2008). Passive BCIs are not based on intended actions of the user, but instead on reactive states of the user's cognition automatically induced while interacting in the surrounding system. Hence, the underlying features used by pBCIs are mostly independent of the primary mode of interaction within a human-machine system (see Table 39.1).

We designed several applications following this approach. Here we present briefly the results from a study, which shows the capabilities arising from the use of passive and secondary BCI interaction in the context of errors in automated adaption.

Table 39.1: Different types of Brain-Computer Interfaces. The classical definitions of active and reactive BCIs are augmented by the definition of passive BCIs. These benefit from high classification rates and a low usage effort

Type of BCI	Based on features from	Used for
active	dedicated action encoding a command. Focussed on directly generating a BCI detectable signal.	direct control
reactive	dedicated perception on an exogenous stimulus. Focussed on indirectly generating a BCI detectable signal.	direct control via external stimuli
passive	changes in cognition resulting from interaction state without any additional effort.	implicit interaction, user-state detection

Errors in communication are highly relevant factors regarding the efficiency of human-machine systems – especially those in automated adaptation of the machine to the interaction mode of the user (PARASURAMAN et al. 2000). A wrong decision induces effects of surprise and frustration and in this respect, adaptation reduces the performance and the safety in human-machine system (SARTER et al. 1997). Additionally, it triggers a correction action which enforces a shift in the intention of the user, and reduces the overall acceptance of the adaptation and of the whole system.

6.2 Experimental Study

6.2.1 BCI System and Experimental Design

To record the electroencephalogram (EEG) of the subjects, 32 channels of Ag/AgCl (EasyCap) electrodes, amplified the signals by a BrainAmp DC system and recorded by the BrainVision Recorder (BrainProducts) were used. The electrodes are distributed over relevant areas on standard 10/20 based caps with 128 positions. Features from the EEG data have been extracted by a derivate of the pattern matching algorithm (BLANKERTZ et al. 2003) extended for detection of several extrema of Event Related Potentials (ERPs). ERPs are local low-frequency polarity changes (1–5 Hz) in the EEG. First, the raw EEG data for a trial is preprocessed. Then, a short feature vector is extracted from the preprocessed data. Finally, a classifier is employed to map from the feature vector to a binary decision value.

6.2.2 The RLR-Game

To investigate the application of pBCIs for solving problems resulting from automated errors, the RLR-game was designed. It mimics the interaction in a human-machine system and allows modelling an unexpected and negative effect, the error state.

In the RLR-game the letter L or R on a starting position has to be rotated left or right wise (by pressing a key on the left or right side of the keyboard) until it corresponds to a given target position. The letters L or R indicate the direction of rotation. While the color of the stimulus is grey, it can not be rotated. However, every 1000 ms the color of the letter changes into green or red, indicating the possibility to rotate the letter by a key press and concurrently the degree of rotation. There are two modes of the game, correct and error (see Fig. 39.4 for details).

In both modes the subject has to develop an efficient strategy for reaching the goal, to rotate the letter as fast as possible onto the target position without rotating it too far. In this setting, two players play against each other. Their performance is measured and fed back in points. A player gets a point when he or she arrives at the target position earlier than his or her opponent.

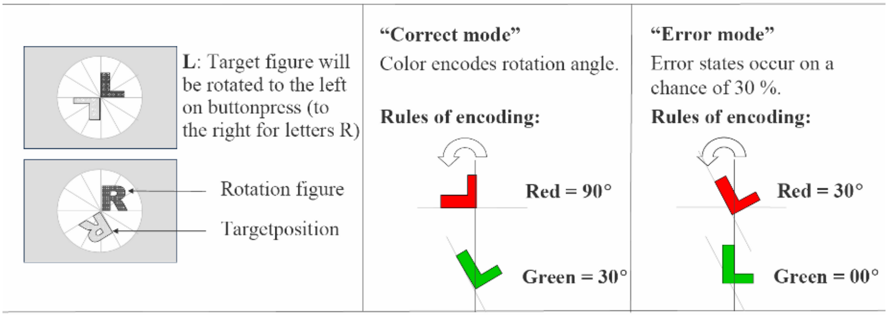

Fig. 39.4: The RLR-Game and its two modes, correct and error

While this game is based on common interaction channels (the key presses) we added a secondary and passive BCI channel capable of correcting the effect of error states. This correction is triggered by an ERP reflecting the mental processing of an error trial. If it is correctly detected by the pBCI during an error trial, the rotation angle is set to the correct mapping. In case of a false positive the angle is reduced to that of an error state. Each correct detection of an error speeds the player up and a false positive slows him or her down.

For keeping the environment as naturalistic as possible, we choose the Open House of the Berlin University of Technology as the setting. Four different pairs of players from the audience played the game against each other. Each pair played three sessions of 50 trials. Session one was without error states and was used for user training. In the second session, error trials were introduced and used to train the classifiers on the data of one of the two players. The automatic adaptation was then applied in the last session for this player.

6.2.3 Results

In Fig. 39.5 the results from the four pairs of participants during the Open House of the Berlin University of Technology in 2007 are shown. The bars represent the difference in points of the two players for each of the three sessions. Positive differences are an advantage for the player wearing the EEG. As expected, there are only small differences between session one and two. But for all four pairs an increase in points can be seen for the third session, the pBCI condition, with the automatic adaptation to the error signal detected in the EEG.

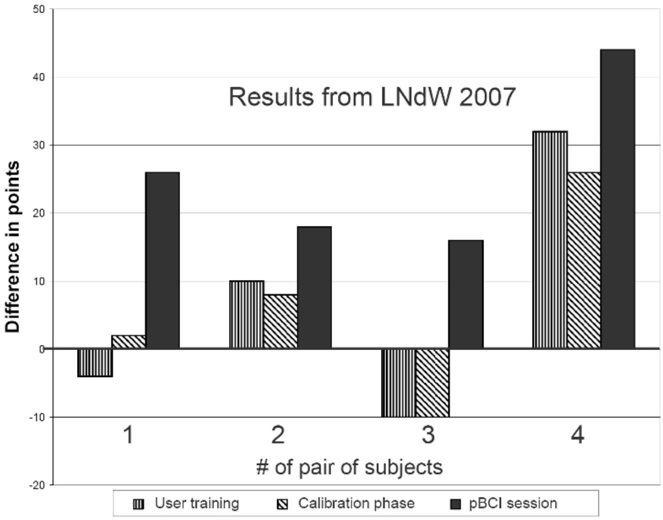

Fig. 39.5: Results from the Open House of the Berlin University of Technology. Players supported by the pBCI clearly enhanced their performance, without the need of any usage cost

6.3 Discussion

In this example of a pBCIs, an information flow from the human brain to the human-machine system was established, reflecting user states that are correlated to the current modes of interaction. It allows extracting the user's actual internal interpretation of dedicated system states from the user's cognition.

In the context of BCI it can be applied to enhance classification accuracy by correcting machine errors as proposed in BLANKERTZ et al. (2003) and FERREZ and MILLAN (2007). For applications in the field of human-machine systems, this method provides information about the user (e.g., emotional state, workload), which normally could not be inferred by typical information channels in traditional human-machine systems. Especially, the idea of utilizing the human brain as a sensor for the subjective interpretation of current states within the human-machine system seems to be a very promising one. The study presented here is a starting point for a whole series of new approaches. Other ongoing studies investigate pBCIs in the context of the detection of mental workload, the cognitive interpretation of the perception of human movements (GAERTNER et al. 2008), cognitive correlates to the perceived loss of controllability (JATZEV et al. 2008) and deriving information about a car driver's intentions.

7 Conclusion and Outlook

Our experiences with pBCIs show that they enable new channels of information within the interaction between human and machine. The passive BCI approach aligns with the idea of implicit interaction in general. Within this context, the utilization of information directly inferred from cognitive processes allows for completely new insights into and applications based on the interaction of human and machine.

Similarly, eye movements can be used to derive information about the interest, the intention and the workload of a person interacting in a human-machine system.

The combination of both techniques, BCI and eye movements, could result in even greater advantages compared to the use of one technology on its own. This form of multi-modal interaction using explicit and implicit exchange of information opens a new and wide range of applications. It might lead to new types of machines that allow an intuitive and more natural interaction between a user and the machine.

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Part 6
Sensorimotor Control of Tools

40 Design and Evaluation of an Augmented Vision System for Self-Optimizing Assembly Cells

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1 Introduction

In high-wage countries many manufacturing systems are highly automated. The main aim of automation is usually to increase productivity and reduce personnel expenditures. However, it is well known that highly automated systems are very investment-intensive and often generate a non-negligible organizational overhead that is mandatory for production scheduling, numerical control programming or system maintenance, but does not directly add value to the product to be manufactured. Highly automated manufacturing systems therefore tend to be neither efficient enough for small lot production (ideally one piece) nor flexible enough to handle products to be manufactured in a large number of variants. In order to achieve a sustainable competitive advantage for manufacturing companies in high-wage countries with their highly skilled workers, it is therefore not promising to further increase the planning orientation of the manufacturing systems and simultaneously improve the economies of scale. The primary goal should be to wholly resolve the so-called polylemma of production, which is analyzed in detail in the contribution of KLOCKE (2009) to this Festschrift.

In general, the polylemma can be resolved through a simultaneous optimization of the conflicting objectives of planning orientation vs. value orientation of activities undertaken, as well as economies of scale vs. economies of scope. However, in the given cases of highly automated manufacturing systems in industry, multi-criteria optimization is very challenging due to a poorly predictable and highly dynamic environment. In most cases, neither a closed-form solution nor a good numerical approximation is available and therefore human skills and knowledge are crucial for optimizing the whole system. Through proactive and anticipatory human intervention, the optimum operating point of the

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manufacturing system can be approached quickly and large deviations from the optimum avoided.

It is well known that the development of skills and knowledge of experienced machining operators can be significantly supported through ergonomic human-machine interfaces (LUCZAK et al. 2003). Within the Cluster of Excellence "Integrative Production Technology for High-Wage Countries" at the Faculty of Mechanical Engineering of RWTH Aachen University, a research project has been established to study self-optimizing assembly cells and to design innovative ergonomic human-machine interfaces (HMI). A novel architecture of the cell's numerical control based on the popular cognitive architecture SOAR (see LEIDEN et al. 2001) forms the technological basis of this approach. The cell's numerical control is termed a cognitive control unit (CCU) which is able to process procedural "knowledge" encoded in production rules and to control multiple robots. Thus, the CCU is able to take over tasks from the machining operator, which are repetitive, dull, dangerous and not too complex, and to cooperate with the human on a rule-based level of cognitive control.

Clearly, knowledge-based behavior in the true sense of RASMUSSEN (1986) (and also skill-based behavior to a large extent) cannot be modeled and simulated by the CCU and therefore the experienced machining operator (German: Facharbeiter) plays a key architectural role in the concept of self-optimization. The system design allows the machining operator to focus on creative and mentally demanding activities such as setting goals and defining constraints as well as goal-directed intervention if assembly errors that are critical to production or system faults occur. The functionality of the HMI thus goes beyond the conventional information input, execution of commands and display of system states, but also includes functionalities for flexible goal specification, task scheduling and a supervisory control system for assembly robots. In the long run, the novel HMI design aims to amplify human performance in self-optimizing assembly cells, increase occupational safety and reduce mental and physical workload.

2 Background

In industrial engineering and ergonomics the term optimization refers to the study of problems in which the human operator seeks to minimize or maximize a (self-developed) single-criterion or multi-criteria objective function representing key performance indicators such as productivity, utilization or safety of the work system by systematically choosing the right values of decision variables from within an allowed set. If the problem can be adequately represented by a mathematical model, a global optimum can be found and additional human intervention is not needed. However, due to the inherent complexity of real manufacturing systems there are many ill-posed problems (VAPNIK 2000), meaning that small changes in the errors can lead to big changes in the optimal parameters. In this case human skills and knowledge are required to find a reachable and stable operating point of the manufacturing system that is close to the anticipated global optimum and to influence the state variables effectively, so that the operating point does not largely deviate from the optimum.

It is important to point out that the concept of self-optimization goes beyond the traditional view of choosing the right values of decision variables and self-adapting the control parameters. Self-optimization aims at the endogenous adaptation of system objectives in terms of a proactive countermeasure to exogenous influences of the manufacturing environment and its fluctuations. This leads to autonomous adjustments of the system structure or work processes and consequently of the manufacturing system's complete behavior (GAUSEMEIER 2008). For instance, self-optimizing assembly cells can develop and adjust their own objective functions, constraints and production rules for safe and productive cooperation between the machining operator and the assembly robots and are able to self-organize error handling and fault diagnosis. Self-organized error detection, identification and recovery are especially important on the shop floor since even a CCU as a next-generation robot controller is likely to face critical system states that cannot be resolved by forward and backward concatenation of production rules alone and where human perception, cognition and sensorimotor control are required to bring the system back to the desired operational state.

2.1 The Role of the Human Operator in Self-Optimizing Assembly Cells

In the classic supervisory control of automated manufacturing systems, the role of the human operator includes planning what needs to be done, teaching the system what it needs to know in order to manufacture, monitoring the system state during runtime to detect trends, errors or failures, intervening in the system if necessary to make adjustments or changes, and finally learning by evaluating the system state and behavior (SHERIDAN 2002). In the case of a self-optimizing assembly cell with a CCU that is able to autonomously decide which part of a given task can be processed by a given system function, the classic role of the human operator has to be revised somewhat. A corresponding model for the coarse-grained function allocation between the operator and the CCU is shown in Fig. 40.1.

When a manufacturing order is assigned to the cell, a so-called master assembly schedule has to be developed by the machining operator first. This master assembly schedule primarily consists of a formal description of the desired final state of the product to be assembled and a set of useful heuristics to reach this goal. If the schedule is properly designed, the goal state can be decomposed and interpreted by the CCU autonomously. Moreover, manufacturing constraints such as maximum lead and cycle times, maximum energy consumption, minimum accuracy etc. must be specified by the machining operator in advance. When the goal state, the heuristics and the associated constraints are submitted to the CCU, assembly procedure planning and teaching (in terms of robot control programming) are carried out on the basis of stored process knowledge that is encoded in rules (see Fig. 40.1).

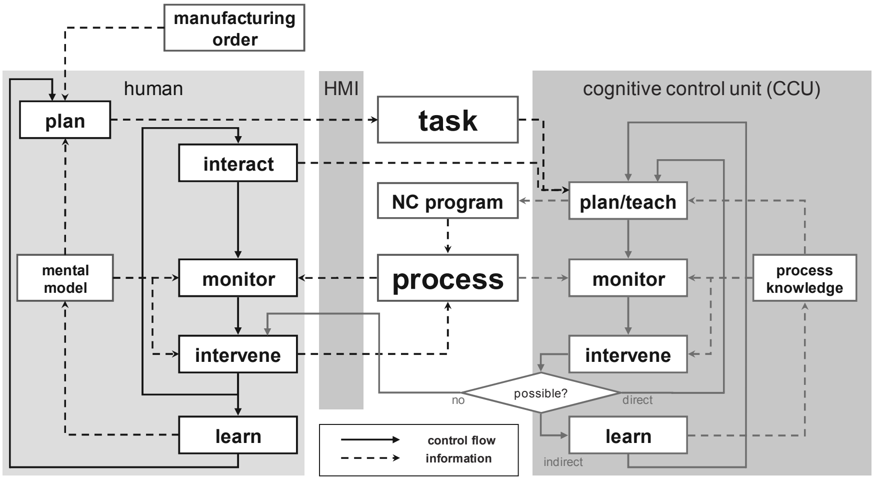


Fig. 40.1: Function allocation between human operator and cognitive control unit in self-optimizing assembly cells (MAYER et al. 2008)

Clearly, the knowledge base must be developed by the operator and the production engineers and it must be regularly maintained. In contrast to Sheridan's classic supervisory control model (SHERIDAN 2002), detailed planning and teaching are included as inherent functions in the CCU. During runtime the assembly process is also continuously monitored by the CCU. The human operator only has to monitor the system and its environment for a possible violation of boundary conditions or dissatisfied constraints and intervene accordingly. In the case of an automatic intervention by the CCU due to a significant assembly problem, three distinct cases have to be considered:

- A solution can be found directly through the application of procedural knowledge in the knowledge base. The goal-oriented adaptation of the detailed assembly schedule and the re-teaching of the robots can be performed autonomously by the CCU and the human is informed accordingly.
- None of the rules in the knowledge base can be directly applied, but the existing problem can be decomposed into sub-problems for which adequate rules exist. The partial solutions can be associated and integrated into the knowledge base as new rules and can be applied the next time this particular problem arises. The system regulates itself and the operator is kept in the loop to develop, verify and validate new rules.

- A solution can neither be found directly nor can it be found by decomposing the problem into sub-problems. In this case the machining operator is needed as a truly intelligent problem solver and supervisor. The missing procedural knowledge can be added to the system by the operator. In this case, the CCU will be able to regulate itself the next time the problem occurs and keep the operator in the optimization loop. Otherwise, the CCU may present an adequate case to the human operator the next time a similar case occurs and thus supports human problem solving and decision making.

Since the CCU is able to resolve a certain class of assembly problems autonomously and therefore significantly relieve the operator from repetitive and monotonous task processing, classic approaches to human-centered automation proclaiming a continuous involvement of the operator (BILLINGS 1991) are not very meaningful in self-optimizing assembly cells. Nevertheless, one has to carefully consider the so-called Irony of Automation (BAINBRIDGE 1987). In case of non-autonomously solvable manufacturing problems, the human operator needs to be in the loop and must have detailed knowledge about the state of the robots, the already executed machining tasks, and the system's objectives and constraints in order to make good or even close to optimal decisions. To cope with this inherent complexity, an important basic requirement for the ergonomic design of the CCU is conformity with the operator's expectations, especially in low level decision-making relating to the product to be assembled, where the human operator is not continuously involved.

2.2 Design of an Experimental Self-Optimizing Assembly Cell

In order to study human-machine interaction in self-optimizing assembly systems, an experimental assembly cell was designed and a manufacturing scenario developed within the cited Cluster of Excellence at RWTH Aachen University (KEMPF et al. 2008). In the scenario, two robots carry out a certain repertoire of coordinated pick and place operations with small workpieces. The 3D model of the prototypical cell is shown in Fig. 40.2. In this article, only the subtask of human intervention due to a severe assembly error by a single robot is analyzed and additional interesting functions of the CCU concerning interactive specification of goals, constraints and tasks are not considered. In order to be able to formulate scientific hypotheses in the next section, it is assumed that the CCU has planned, executed, and monitored a sequence of assembly tasks up to the point when the assembly error occurs. The fact that an error has occurred is detected by the CCU due to the blocking state of the robot in question, but it is assumed that it cannot qualitatively describe or locate the error due to a lack of sensor information. Therefore, the machining operator first has to detect and identify the assembly error using his/her own senses and mind. He/she then has to manually intervene and correct the assembly error in order to finish the manufacturing step and reduce the down time of the assembly cell, but for the sake of simplicity this procedure is not considered in this article.

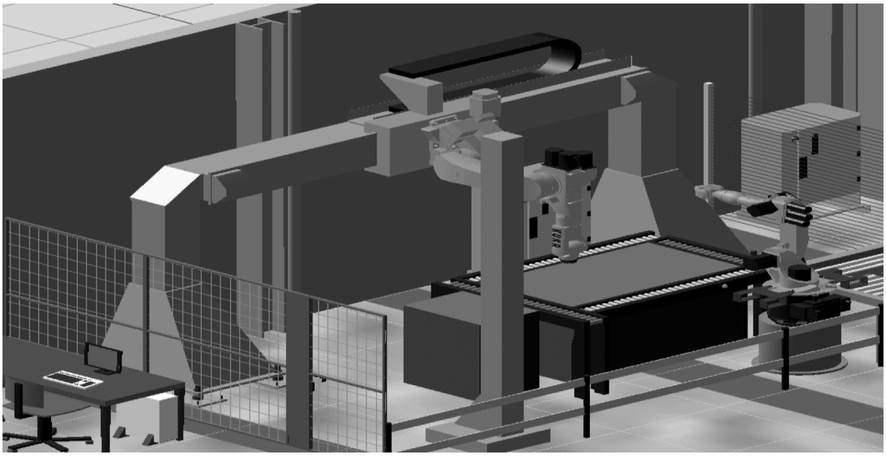


Fig. 40.2: 3D model of the self-optimizing assembly cell

In order to detect the assembly error, the human operator has to compare the partially assembled part in the working area of the robot to the goal state. The goal state is usually represented in the form of technical drawings of the semi-finished or finished part. When using conventional paper-based drawings, the human operator has to change the point of eye fixation frequently and shift attention between the assembled part and the corresponding drawings. He/she may also have to adapt to different luminous intensity levels of the part and the drawings as well as to search for details that are printed on different pages. A further practical disadvantage of the conventional error detection and identification procedure is that the human operator often needs to have at least one hand free to hold the drawings since a clean and planar surface is not always readily available nearby on the shop floor.

WIEDENMAIER (2004) investigated the effectiveness of different kinds of information presentation and interaction when assembling a car door. He compared paper-based drawings, virtual drawings as 3D models which were superimposed on the field of view of the operator, and step-by-step instructions directly given by a human assembly expert. The superimposition of virtual objects on the field of view was achieved by a so-called video see-through display which was mounted to the user's head (head-mounted display, HMD). This mode of information presentation is also termed a visual augmentation. More details about visual augmentation, the corresponding display technologies and ergonomics of HMDs can be found in SCHLICK et al. (2008). The results of WIEDENMAIER (2004) show that when comparing the paper-based and virtual drawings, an ergonomically well-designed visual augmentation leads to a shorter time-on-task, better assembly quality and lower workload. TANG et al. (2004) carried out a similar study that also included the presentation of assembly instructions on a commercial off-the-shelf TFT liquid crystal display. Although no significant effects concerning the time-on-task were found, the accuracy of task execution increased significantly through the visual augmentation. A significant increase in accuracy when working with superimposed assembly information is also reported in MEYER et al. (2005).

Additional research on visual augmentation in manual assembly dealt with the legibility of virtual assembly instructions within the field of view. For instance, LUCZAK and OEHME (2004) and OEHME (2004) investigated different font and symbol sizes for various optical see-through HMDs such as TFT liquid crystal displays and laser retinal displays.

In the manufacturing scenario described above a very high-resolution stereoscopic HMD is worn by the operator during the process of assembly error detection and identification. The display is used in a see-through mode with two optical combiners (half-silvered mirrors) as the primary optical elements in front of the left and right eye of the user. Thus, the operator's "natural view" of the scene can be augmented by synthetic assembly information. The images for the two optical combiners are generated separately by the display computer on the basis of interpupillary distance, head position and scene geometry, so that an accurate superimposition of synthetic assembly information is possible. An infrared tracking system is used to determine the position and orientation of the operator's head in real time (NEUHÖFER et al. 2008). Such an Augmented Vision System either allows assembly information to be statically displayed or for it to be dynamically aligned with the field of view. Because the focus of the system design is on human perception and information processing and not on computer graphics, it is termed an Augmented Vision System in the following sections.

3 Laboratory Study of an Augmented Vision System for Assembly Error Detection and Identification

The laboratory study of the described Augmented Vision System aimed to answer the following research questions:

- Does the accurate closed-loop superimposition of synthetic assembly information on the operator's field of view have a significant influence on error detection time or error detection frequency?
- Do different presentation modes of superimposed synthetic assembly information have a significant influence on error detection time or error detection frequency?

3.1 Methods

3.1.1 Stimuli

On the basis of common techniques for designing written assembly instructions derived from the domain of technical writing (see ALRED et al. 2003), different modes of visual presentation (and interaction) were designed and developed. Clearly, an ergonomic presentation of assembly instructions is of great importance and can significantly contribute to safety, productivity and user satisfaction. In general, assembly instructions consist of a synthesis of various types of information: exploded views of parts to be assembled, textual or graphical step-by-step instructions of the assembly procedure, wiring diagrams, schematics, rules, shipment, assembly tools etc. (see INABA et al. 2004, ALRED et al. 2003, JUHL 2005). Because the focus of this study is on the detection and identification of assembly errors by the human operator – and initially ignores the error correction and recovery process that is required later – only exploded views and graphical step-by-step instructions are considered (ODENTHAL et al. 2008). An exploded view shows the physical form of the basic components of an assembly and these components are slightly radially shifted from the center of gravity of the complete object. The graphical step-by-step view simply shows the state progression of the physical form during the buildup of the assembly with a minimum number of spatial rotations and translations of the basic components.

In order to present high quality assembly information and therefore allow fast and accurate error detection with a low level of mental workload, the parts were modeled accurately as 3D solids and were displayed in 3D stereo. To simplify the CCU design of the prototypical assembly cell already depicted in Fig. 40.2, the research in the first phase of the project focused on assembling plastic models with the popular LEGO bricks. This experimental approach has two main advantages: (1) The standardized and colored LEGO bricks can be grasped, moved and positioned quickly and accurately by the robots without danger for the operator; (2) Assembly schedules can be synthesized for arbitrary, complex LEGO models on the basis of the SOAR cognitive architecture with only a small number of motion operators which are easy to understand for the human (see MAYER et al. 2008).

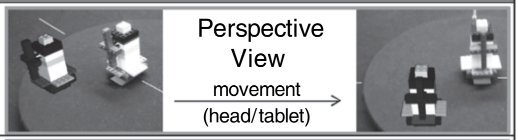
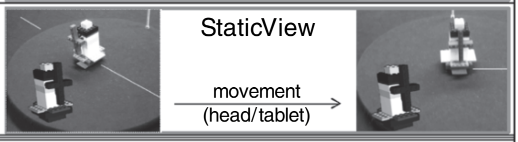
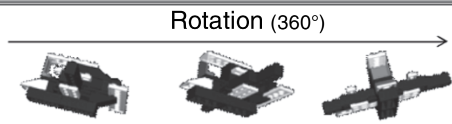
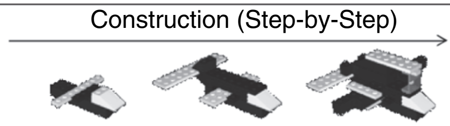
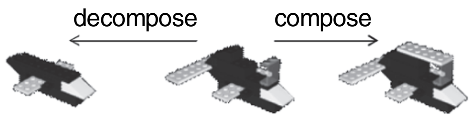
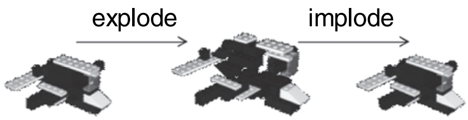
3.1.2 Experimental Design

The experimental design distinguishes three factors representing different modes of presentation (and interaction) of the synthetic assembly information:

1) the so-called augmented vision mode (factor AVM),
2) the a priori presentation of the goal state of the completely assembled LEGO model (factor APP), and
3) the mode for interactively decomposing and composing the LEGO model during the error detection and identification process (factor DCM).

A full factorial within-subject design with two experimental conditions in each factor was applied. The experimentally determined factors and the associated experimental conditions are summarized in Table 40.1 and explained below.

Table 40.1: Factors and factor levels in the laboratory study

Factors	Levels	Examples
Augmented Vision Mode (AVM)	Perspective View	
	Static View	
A Priori Presentation of Complete Model (APP)	Rotation	
	Construction	
Decomposition/ Composition Mode (DCM)	Step-by-Step	
	Exploded View	

- Augmented Vision Mode (AVM):
  With the infrared optical tracking system the position and the orientation of the HMD can be measured in real time and the user's viewing direction can be estimated. Moreover, the real LEGO model's position and orientation in front of the user can be determined and it is therefore possible to accurately superimpose the virtual model on the field of view in a closed-loop. On the other hand, this "perspective view" (Table 40.1) requires expensive tracking equipment and can only be justified on the shop floor if it entails significant performance or workload advantages. For this reason, a simple static information presentation was investigated as well as the enhanced augmented

vision mode. Hence, the two factor levels are: (1) Perspective View: The virtual LEGO model is aligned with the position and orientation of the real object in the field of view and is positioned to its left at a distance of 4 cm. A motion of the real model or a head movement leads to a redrawing of the virtual model, so that the perspectives accord. (2) Static View: In this case the virtual LEGO model is fixed to a position relative to the screen coordinates of the HMD. In the experiments, the virtual object was displayed at an inclination angle of 20° to its vertical axis in the third quadrant of the binocular screens.

- A Priori Presentation (APP):
  For the mode of a priori presentation of the goal state of the completely assembled LEGO model (before the assembly error had to be detected and identified) two factor levels were distinguished: (1) Rotation: the completely assembled virtual LEGO model rotates once on a predefined rotation axis at an inclination angle of 20° and with an angular velocity of 3.2 seconds for 360°. (2) Construction: the virtual model is composed step-by-step by single bricks with a cycle time of 1.2 seconds per element.

- Decomposition/Composition Mode (DCM):
  For the mode of interactively decomposing and composing the LEGO model at will on the basis of the underlying bricks during the error detection and identification process two levels were analyzed: (1) Step-by-step: the user can interactively decompose or compose the virtual LEGO model in relation to the goal state in a step-by-step and self-paced way using two keys on a tablet. (2) Exploded view: the user is able to interactively either explode or implode the virtual model using a different key on a tablet.

3.1.3 Apparatus

Figure 40.3 shows the main components of the developed Augmented Vision System used for this experiment. The LEGO models with the assembly errors to be detected and identified were placed on a small turntable that was mounted on a conventional assembly table in the center of the field of view (Fig. 40.3, left). The subjects sat in a comfortable upright position on a chair when using the Augmented Vision System. The position and orientation of the HMD and the small turntable were tracked by the infrared real time tracking system smARTtrack (A.R.T. GmbH).

A binocular HMD of the type nVisorST manufactured by NVIS Inc. was used to display the synthetic assembly information. The resolution of its embedded liquid crystal on silicon displays is 1280 × 1024 pixels with an adjustable brightness of 30 fL maximum and a see through transmission of 40%. The total weight of the HMD with the attached markers for optical tracking is approximately 1.3 kg. A color marker pen was used by the subjects to mark the assembly error directly by hand on the corresponding LEGO brick. The pen was located behind a transparent lid (Fig. 40.3, top right). When grasping the pen behind the lid, a microswitch connected to the lid registered the point in time of error detection and identification. The keys for manipulating the virtual LEGO models were mounted on a magnetic key tablet (Fig. 40.3, top right). The key assignment was as follows: (1) step-by-step composition/decomposition of the model (factor DCM, level 1) with the keys at the top and bottom, respectively; (2) toggling between the exploding and imploding mode (factor DCM, level 2) with the left key, (3) repetition of the a priori assembling sequence (factor APP) could be triggered with the key on the right.

Fig. 40.3: Main components of the Augmented Vision System. The HMD and a real assembly model on top of the small turntable are shown on the left. The tablet with the keys for manipulating the virtual models as well as the box holding the color marker pen are shown in the top right-hand picture. A user wearing the HMD is depicted in the bottom right-hand picture

3.1.4 Procedure

The procedure was divided into two main phases:

(1) Pretests and training under experimental conditions

First, the personal data were collected, e.g. age, profession, experience with computers, experience with virtual and augmented reality systems as well as assembly skills relating to LEGO models. Second, three vision tests were carried out using a Rodatest 302 system (Vistec Vision Technologies):

- o Visual acuity test according to the German standard DIN 58220 on the basis of Landolt rings for 6 m, 50 cm and 40 cm distances (right eye, left eye and binocular);
- o Stereo vision test (binocular, distance of 55 cm);
- o Ishihara color test (test for red-green color deficiencies, binocular, distance of 55 cm).

The subjects were selected according to their scores in the stereo vision test and the Ishihara color test. Further, their eyes had to be in a state of emmetropia meaning an object at infinity is in sharp focus with the eye lens in a neutral or relaxed state.

Third, a questionnaire on visual fatigue according to BANGOR (2000) was carried out. It is well known that wearing HMDs can quickly lead to visual fatigue and therefore significantly influence human performance, workload and well-being (PFENDLER & SCHLICK 2007). The questionnaire includes 15 items to assess nausea, headache etc. Each item had to be rated on a discrete scale ranging from 0 (not noticeable at all) to 10 (extremely noticeable).

After completing the pretests, a fourth sub-phase of 10 minutes followed. In this sub-phase the subjects were trained to use the Augmented Vision System under the experimental conditions described.

(2) Data acquisition

Each subject conducted eight trials. The procedure was as follows:

- o Start of trial by the a priori presentation of the goal state of the LEGO model under consideration. According to the previous definition of factor APP this presentation was either a rotation of the complete virtual model or it’s step-by-step construction. The virtual assembly sequence was presented to the subjects without having the real object in their field of view.
- o After the a priori presentation of the goal state, the real model with the assembly error was presented on the small turntable by the experimenter. It was possible to manipulate the corresponding virtual object with the keys on the tablet either by decomposing/composing it stepwise or by exploding/imploding it (factor DCM). The subjects could replay the a priori sequence in full length during the trial, but were not able to abort the sequence or further manipulate it.
- o After each case of detection and identification of the assembly error of the real LEGO model, the erroneous brick had to be marked with the color marker pen and the difference written down on an error identification sheet. As the participant did not know the type of assembly error in advance, it was possible that he/she could not find any difference

between the real and the virtual LEGO model. In this case, this also had to be indicated on the error identification sheet.
  - o Finally, in the post test phase the participant had to take the HMD off and complete the cited questionnaire on visual fatigue

The total time-on-task was approximately two hours for each participant. The subjects were balanced with respect to the experimental conditions.

3.1.5 Subjects

A total of 24 subjects, 16 male and 8 female, participated in the laboratory study. All of them satisfied the cited requirements concerning stereo vision, color vision and emmetropia. The age of the subjects was between 19 and 36 years (mean 26.8 years, SD 4.4). 90% of the subjects use a personal computer daily. 54% of them stated that they had no or little experience with virtual or augmented reality systems. 37.5% of the subjects had prior experience with 3D computer games. The average weekly playing time was approx. 4 hours. The average experience in assembling LEGO models was 3 (SD 1.4) on a scale ranging from 0 (low) to 5 (high). Eight subjects reported having problems in the past after working with electronic information displays: there were four cases of headache, two of eyestrain, one of blurred vision, and one of dry eyes.

3.1.6 Dependent and Independent Variables

In accordance with the experimental design, three independent variables were distinguished:

- Augmented vision mode (perspective or static view)
- A priori presentation of the goal state of the completely assembled model (rotation or construction)
- Decomposition/composition mode (step-by-step or exploded view)

The following three dependent variables were considered:

- Detection time
  The detection time is the time that elapses from the start of the trial until either an assembly error is detected and identified by the participant or the participant indicates the absence of an assembly error. The start and finish events were measured by the apparatus described above. The detection time was limited to a maximum of 15 minutes.
- Quality of error detection in terms of
  - o frequency with which the participant detected and identified the error correctly by marking the correct brick on the real model,
  - o frequency with which the participant detected and identified the error incorrectly by marking an incorrect brick on the real model, and
  - o frequency with which the participant did not detect the error.

- Visual fatigue
  The visual fatigue was assessed with the help of the cited visual fatigue questionnaire of BANGOR (2000). The pretest results served as the baseline for the post-hoc fatigue assessment.

3.2 Null Hypotheses and Statistical Analysis

The following null hypotheses were formulated:

- The augmented vision mode (H_{01}), the a priori presentation of synthetic assembly information (H_{02}) and the decomposition/composition mode of the virtual model (H_{03}) do not significantly influence the detection time.
- The augmented vision mode (H_{04}), the a priori presentation of synthetic assembly information (H_{05}) and the decomposition/composition mode of the virtual model (H_{06}) do not significantly influence the frequency of correctly detected and identified errors.

A three-way analysis of variance (ANOVA) with repeated measures was calculated to test the hypotheses H_{01}, H_{02} and H_{03}. The detection time data were log-transformed before the ANOVA was carried out (see FIELD 2005). The significance level was set at $\alpha=0.05$. The Kolmogorov-Smirnov test was used to test the normality of the log-transformed time data. Chi-square tests were calculated to test the hypotheses H_{04}, H_{05} and H_{06}. The significance level was also set at $\alpha=0.05$.

3.3 Results and Discussion

3.3.1 Detection Time

The log-transformed detection time data did not show a significant deviation from normality. The results of the three-way ANOVA are shown in Table 40.2. The means of the detection times under the different experimental conditions including the 95% confidence intervals are shown in Fig. 40.4.

Table 40.2: Results of ANOVA of detection time

Source	SS	df	MS	F	p
AVM	0.8318	1	0.8318	8.0880	0.0094*
Error(AVM)	2.2626	22	0.1028		
APP	0.0044	1	0.0044	0.0474	0.8297
Error(APP)	2.0348	22	0.0925		
DCM	0.0001	1	0.0001	0.0013	0.9716
Error(DCM)	1.7039	22	0.0775		
APP * DCM	0.1957	1	0.1957	1.1075	0.3040
Error(APP*DCM)	3.8875	22	0.1767		
APP * AVM	0.0606	1	0.0606	0.4661	0.5019
Error(APP*AVM)	2.8607	22	0.1300		
DCM * AVM	0.0326	1	0.0326	0.2543	0.6191
Error(DCM*AVM)	2.8170	22	0.1280		
APP * DCM * AVM	0.0301	1	0.0301	0.1223	0.7299
Error(APP*DCM*AVM)	5.4072	22	0.2458		

*p < 0.05

Under the perspective view condition of the augmented vision mode (AVM), the average detection time was 29.61% shorter than in the case of a simple static view. This difference is statistically significant ($F(1,22) = 8.0880$, $p = 0.0094$). Regarding the factor levels encoding the a priori mode of assembly information presentation (APP), the rotation condition led to an average detection time that was 18.19% shorter than under the alternative construction condition, but this difference is not significant ($F(1,22) = 0.0044$, $p = 0.9297$). The average detection times under both conditions of the decomposition/composition mode (DCM) were only slightly different. When working with the exploded view the average reaction time was 2.78% shorter which is also not significantly different ($F(1,22) = 0.0013$, $p = 0.9716$). Statistically significant interactions were not found.

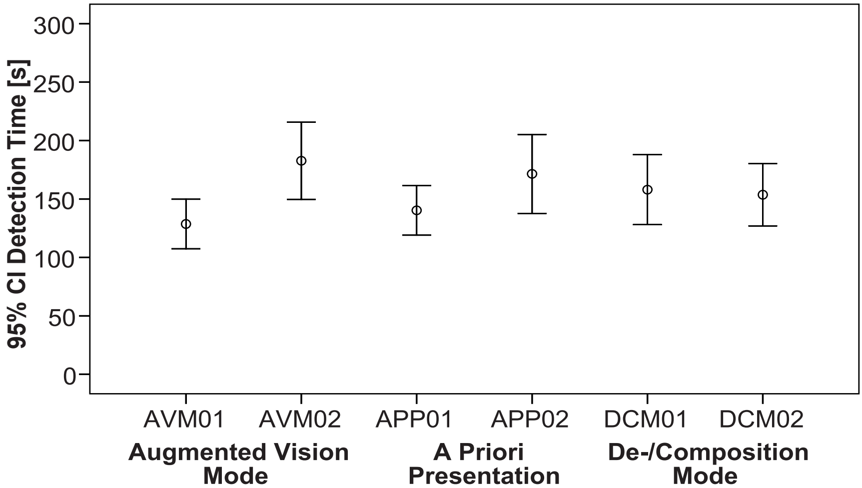


Fig. 40.4: Detection times [s] under the experimental conditions

3.3.2 Frequency of Errors

The contingency tables of the frequency of errors are shown in Table 40.3. The corresponding test results are given in Table 40.4. When comparing both augmented vision modes, the perspective view mode led on average to a 19% higher frequency of correctly detected and identified errors than the static view mode. A rotating LEGO model for the a priori presentation of the product structure enabled the users to detect and identify 16% more errors correctly than under the alternative step-by-step construction. The frequency difference between step-by-step decomposition/composition and the exploded view was considerably smaller (6%) for correctly detected and identified errors. However, these frequency differences are not significant. According to Table 40.4 the frequencies of the other error categories of incorrectly or not detected errors are also not significantly influenced by the independent variables.

Table 40.3: Contingency table of error detection frequencies under the experimental conditions

		Error detection			
		Error correctly detected	Error incorrectly detected	Error not detected	Total
Augmented	AVM01	74	4	18	96
Vision Mode	AVM02	62	8	26	96
A Priori	APP01	63	6	27	96
Presentation	APP02	73	6	17	96
De-/Compo-	DCM01	70	4	22	96
sition Mode	DCM02	66	8	22	96
	Total	136	12	44	192

Table 40.4: Results of the chi-square tests

Source	χ^2	df	p
Error correctly detected			
Augmented Vision Mode (AVM)	1.059	1	0.303
A Priori Presentation (APP)	0.735	1	0.391
De-/Composition Mode (DCM)	0.118	1	0.732
Error incorrectly detected			
Augmented Vision Mode (AVM)	1.333	1	0.248
A Priori Presentation (APP)	0.000	1	1.000
De-/Composition Mode (DCM)	1.333	1	0.248
Error not detected			
Augmented Vision Mode (AVM)	1.455	1	0.228
A Priori Presentation (APP)	2.273	1	0.132
De-/Composition Mode (DCM)	0.000	1	1.000

$^*p < 0.05$

3.3.3 Comparison and Discussion of Detection Time and Error Detection Frequency

When the detection times and the error detection frequencies under the different experimental conditions are analyzed, the following conclusions can be drawn:

- Augmented vision mode: The augmented vision mode with an aligned perspective resulted in a lower average detection time. The perspective view also allowed more errors to be detected correctly and less errors incorrectly. Therefore, the data analysis demonstrated no evidence for a speed-accuracy tradeoff. In the static view mode the users frequently had to process a mental rotation of the virtual LEGO model under consideration during the error search, which is a strenuous and time-consuming operation. Since the classic works of SHEPARD and METZLER (1971), it is known that the reaction time taken by a subject to decide if two items match or not is proportional to the rotation angle between them and our data confirms these findings. The reaction time also increased with the complexity level of the presented object (FUNKE & FRENSCH 2006). The perspective view mode enabled a recognition-primed comparison between the goal and the given assembly state without the need to allocate significant cognitive resources for mental rotations or translations.

- A priori presentation: The a priori rotation of the virtual model led to a shorter average detection time, but the frequency of correctly detected errors was also lower than in the case of step-by-step construction. In other words, a speed-accuracy tradeoff occurred. When using the construction sequence to understand the goal state of the assembled object, the subjects could build a more accurate mental model of the product structure and the assembly procedure than in the case of object rotation. However, the rotation of the virtual model allowed the cited strenuous mental rotations to be avoided and led to faster but also more error-prone detection.

- Decomposition/composition mode: The exploded view allowed the users to toggle quickly between the "collapsed" and "expanded" product structure (the inter-event time between state transitions was often less than 1 second in the experiment) and therefore to build an accurate iconic representation in their visual spatial memory. Conversely, the step-by-step mode – especially a bottom-up construction – requires a certain time and mental effort until the error becomes visible. However, the average detection times of both modes revealed only a very small time advantage of 3% for the exploded view, which had been expected to be much larger. This seems to be caused by masking effects rendering the precise error allocation difficult. Conversely, the frequency of correctly detected errors when using an exploded view was lower than in the case of a step-by-step decomposition/composition and the frequency of incorrectly detected errors was higher. In other words, here too a speed-accuracy tradeoff occurred.

3.3.4 Results and Discussion of the Visual Fatigue Questionnaire

As pointed out in the previous section, the data of the visual fatigue questionnaire were collected before starting a trial ($i=0$) and after each trial ($i=1 \ldots 8$). In Table 40.5 the means and the standard deviations of pre-post differences are shown for each item. A difference of 1 represents an increase in visual fatigue of 10%. According to Table 40.5, the largest increase in visual fatigue is just 0.14 for the item “pain in or around eyeball”. The other differences are all smaller than 1% and can therefore be ignored.

The acquired fatigue values are much smaller than expected and show that the ergonomic design of the Augmented Vision System is already quite good. Nevertheless, it is important to point out that the consecutive time-on-task with the worn HMD was only between 0.5 and 13.6 minutes in the experimental study. The error detection and identification phase was always followed by a recovery phase of two to three minutes to fill in the questionnaire without wearing the HMD. It is to be expected that longer load cycles would significantly increase visual fatigue (PFENDLER & SCHLICK 2007).

Table 40.5: Differences between pre and post assessment of visual fatigue

Items of Questionnaire	Mean	SD
Dry eyes	–0.005	0.650
Watery eyes	–0.035	0.650
Eyes are irritated, gritty, or burning	–0.012	0.185
Pain in or around eyeball	0.140	0.884
Heaviness of the eyes	0.050	0.481
Difficulty in focusing	0.000	0.118
“Shivering/jumping” text	0.081	0.673
“Foggy” pictures	–0.067	0.886
Glare from lights	0.026	0.860
Blurry vision	0.046	1.019
Double vision	0.011	1.006
Headache	0.000	1.003
Neck pain	–0.134	0.842
Nausea	–0.013	0.344
Mental fatigue	–0.054	0.701

4 Conclusion and Outlook

Novel models, methods and tools from industrial engineering and ergonomics are required to significantly improve the competitiveness of European manufacturing companies. One promising approach is self-optimizing manufacturing cells (KLOCKE & PRITSCHOW 2004, GAUSEMEIER 2008) based on the knowledge, skills and abilities of experienced human operators. The information processing and decision making of these “Facharbeiter” (highly skilled workers) can be effectively supported through novel human-machine interfaces which are designed on the basis of innovative methods and tools from the domain of cognitive systems engineering (RASMUSSEN et al. 1994, LUCZAK et al. 2001, 2003). In the presented experimental study on human-machine interaction a robotized assembly process was investigated with regard to the decision support of the human operator in the case of an assembly error. For this purpose, an Augmented Vision System was designed and developed. Further, a laboratory study with 24 subjects was conducted to evaluate different presentation (and interaction) modes of synthetic assembly information in the field of view. On the basis of the empirical findings some general design recommendations can be given. Firstly, a perspective view leads to significantly faster detection and identification of assembly errors in a product than a static view, with an average time reduction of 30%. Further, there is a trend indicating additional advantages in detection accuracy and a perspective view is thus highly recommended. Secondly, the a priori rotation of the virtual product enables an average of 18% faster detection of errors than the step-by-step construction, but here one must expect that, on average, 16% less errors will be correctly detected and identified. We recommend starting the error search with an a priori rotation of the goal state and allowing the user to reconsider the goal state later on by choosing either the rotation or the step-by-step construction. Thirdly, the exploded view mode for decomposing and composing the product during the error search revealed only very small detection time and error frequency differences (smaller than 3% and 6% respectively) when compared with the step-by-step procedure. We recommend that both modes can be used alternatively by the operator and to assign the state transitions to different keys. In order to ensure conformity with user's expectations the state transition from a decomposed state to a more composed state should be assigned to an upward-pointing key, whilst the transition from a composed state to a more decomposed state should be assigned to a downward-pointing key. The toggling between the exploded and imploded view on the product structure should be assigned to a single key which allows a fast state switching and therefore simplifies an iconic object representation in the visual spatial memory. In general, the experiments showed that future assembly assistance systems for the machining operator should not try to simulate and automate the very powerful form-forming capability of our senses, particularly with respect to the visual recognition of figures and whole forms, but focus on sensor data fusion and image processing techniques allowing the reliable detection of predefined product features and to visualize the associated component following the metaphor of an X-ray system (BANE & HÖLLERER 2004).

With regard to future ergonomic studies of Augmented Vision Systems for self-optimizing assembly cells, it is of special interest to analyze more complex work processes going beyond the admittedly simple assembly of LEGO bricks. For this purpose several products of medium complexity, e.g. a motorcycle carburetor, have already been analyzed and it is planned to carry out similar laboratory studies which also include robot motion. An additional step towards ergonomic error management is to support the operator in developing a plan for correcting the given assembly error and to bring the assembly cell back into an operational state safely. Due to the significant aging of skilled operators in European manufacturing enterprises it is also of great interest to study age-related effects of visual perception and spatial visual memory when working with Augmented Vision

Systems and to adapt the visualization and interaction modes to individual performance and workload.

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41 Visual Ergonomic Issues of LCD Displays – An Insight into Working Conditions and User Characteristics

Martina Ziefle

1 Introduction

More and more workplaces today depend on the frequent interaction of humans with visual displays. Different from earlier times, in which mostly young and technology-prone users were the major user group of computer work, more and increasingly diverse user groups, e.g. children and older workers, are confronted with electronic work. It is of central importance that electronic displays allow a trouble-free usage and provide a high working productivity. Also, technical developments and improvements necessitate the need to continuously evaluate new technologies with respect to their actual benefit for human performance.

There is quite a long history of studies dealing with the evaluation of visual displays (DILLON 1992; LUCZAK & OEHME 2002). Visual ergonomic studies were concerned with the evaluation of displays and the identification of shortcomings of current display design. The criteria for the suitability of displays for presenting information were users' productivity in terms of speed and accuracy of visual performance as well as the emergence of visual strain (e.g. GOULD et al. 1987a, 1987b; DILLON 1992, 2004; LUCZAK et al. 2003; SCHLICK et al. 2007; SHEEDY & BERGSTROM 2002; ZIEFLE 1998). Over the years a solid visual ergonomic knowledge was gathered with respect to how electronic information should be displayed appropriately. The knowledge regards different sources of influencing factors. A considerable number of studies examined the importance of text factors (e.g. structure, format, and breadth of electronic information) as well as display factors (e.g. contrast, resolution, image quality) on visual performance (e.g. GOULD et al. 1987a,b; OEHME et al. 2001; OETJEN & ZIEFLE 2004, 2007; QIN et al. 2006; SHEEDY et al. 2003; ZIEFLE 2001a,b; ZIEFLE et al. 2003). Also, the impact of visual and cognitive demands imposed by different tasks and prolonged on-screen reading have been examined respecting their consequences for visual performance (e.g.

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GRÖGER et al. 2005; LUCZAK et al. 2003; ZIEFLE et al. 2005; SCHLICK et al. 2007; ZIEFLE 1998). Another prominent research issue referred to the question, which screen type benefits or disadvantages visual performance. The comparison of different display types received special attention lately as screen technology changed. While a few years ago the cathode ray tube (CRT) had been the state-of-the-art technology (LUCZAK et al. 2003; SCHLICK et al. 2007), Liquid Crystal Displays (LCD) replaced the CRTs and represent now the state-of the-art technology. From a visual ergonomic perspective, LCDs have many advantages compared to CRTs. They are lightweight, flicker free and provide higher luminance and contrast levels compared to CRTs. As LCDs have a smaller footprint and weigh less, they can easily be moved on the desk to meet preferred viewing distances onto the display. Also, they can be used for mobile devices. However, LCDs have one major drawback: the displayed information is "perfectly" visible if users work in front of the screen. Whenever this "optimal" position is not present, visibility is distinctly worse. This specific property is called anisotropy. The psychophysical nature of anisotropy is such that photometric measures (contrast and luminance) are not constant over the screen surface, but rather decrease with increasing viewing angle. Anisotropy is given if a display shows a deviation of more than 10% of its luminance subject to the target location or viewing angle (ISO 13406-2 2001). Recent studies show that anisotropy has to be taken seriously. The visual performance when working with LCDs considerably deteriorates when users are looking from 10° to 50° off-axis (GRÖGER et al. 2003; HOLLANDS et al. 2001, 2002; OETJEN & ZIEFLE 2004, 2007; OETJEN et al. 2005; ZIEFLE et al. 2003).

In real life many situations can be referred to in which anisotropy plays an important role. In school contexts it is frequently the case that several pupils are sitting in front of one screen, and naturally extended or off-axis viewing angles are present. In mobile contexts working with notebook computers the probability of extended viewing angles is also high. Other prominent examples are traffic controlling environments or stock exchanges, in which several screens placed in parallel and/or upon one another have to be surveyed by one operator.

Figure 41.1 shows a typical example from a rail control station. In order to avoid train collision, the operator surveys up to six monitors simultaneously and keeps rail tracks and ramifications of different trains and stations under surveillance.

Fig. 41.1: An example of an LCD working place within a rail way control (private photos, OETJEN 2008)

2 Psychophysical Measuring Rationale of Anisotropy

Whenever anisotropy is experimentally investigated, a specific quantification rationale is necessary, which has to meet several methodological demands. The measuring procedure should allow a reliable expression of anisotropy in terms of single components (luminance levels of bright and dark areas). Also, luminance values should be known for different screen positions and result from a standardized procedure, which allows reliable comparisons between and across screens. As anisotropy occurs on the complete screen surface and is not necessarily symmetrical, the measuring must be small-grained and detailed, including different screen positions and viewing angles. Also, it has to be assured that anisotropy is not limited to selected screens but reflect general characteristics of LCDs. To meet these demands, we developed a measurement set-up that enabled us to quantify changes of photometric measures for different viewing angles and relate these to visual performance (GRÖGER et al. 2003; ZIEFLE et al. 2003; OETJEN & ZIEFLE 2007, 2009).

In order to refer to replicable screen locations, the screen was virtually divided into 63 black and white fields (nine lines, seven rows). The ambient lighting was set to 300 Lx during measurement (ISO13406-2 2001) and testing. The luminance of the background (bright areas) was standardised to 100 cd/m², according to ISO 9241-3 (2000). All 63 screen locations were measured by a photometer (Luminance Meter Type 1101, Bruel & Kjaer®, minimum flare angle of 1/3°).

For the understanding of anisotropy it is crucial to consider that the outcomes in photometry depend on how the measurements are carried out. In the measurement procedure that is normally used by the industry the photometer is placed in front of the screen and displaced gradually from field to field (standard measurement, Fig. 41.2, left). Thus, it always has a right angle to the screen surface. These conditions result in luminance values that are quite homogeneous, but do not reflect the actual extent of the divergence of luminance values over the screen surface. The procedure is highly artificial as users do not displace themselves in front of the screen, but rather turn their head (and view). Viewing angles change remarkably depending on where users are looking at. To simulate this behaviour, the photometer adopted two viewing angles: in the central (0°) position the photometer was turned to all 63 screen locations just as it is the case when users are working with the screens (User view, Fig. 41.2, centre).

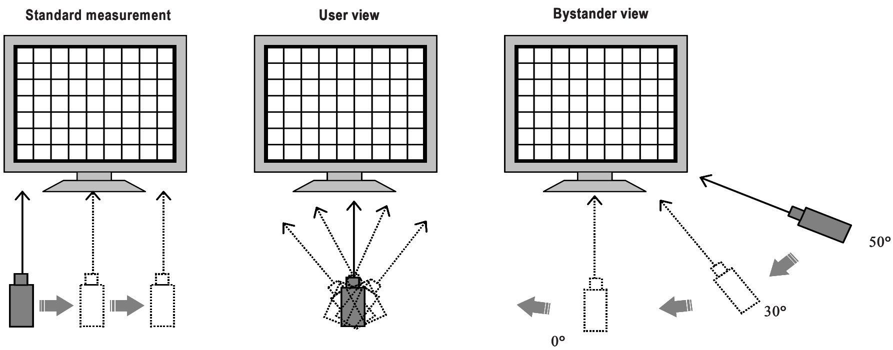

Fig. 41.2: Quantifying anisotropy: Left: "standard view"- the photometer is displaced at right angles; center: "user view"- the photometer emulates users' head movements; right: "bystander view"- the photometer is positioned off-axis (ZIEFLE et al. 2003)

For the extended viewing condition, the photometer was placed in the off-axis position (50°) and its view pointed to all 63 fields of the screen surface from the left and right side, respectively (bystander view, Fig. 41.2, right). This measurement rationale was applied to various screen types (CRTs and LCDs), different screen sizes (15" and 17"), brands and fabrication times (1999 to 2005).

Outcomes show that photometric measures change dramatically as a function of viewing angle (Fig. 41.3). The changes were less pronounced for CRTs (Sony S200PS; Elsa Ecomo Office) than for all LCDs. The most prominent anisotropic effects were observed for the two Notebook-LCDs (Dell 8100; IBM Thinkpad). Characteristically, with increasing viewing angles the luminance of the bright areas is less bright (Fig. 41.3, left). The luminance of the dark areas (Fig. 41.3, right) does not vary monotonically with increasing viewing angle. Overall, it has to be concluded that anisotropy is a general characteristic of LCDs.

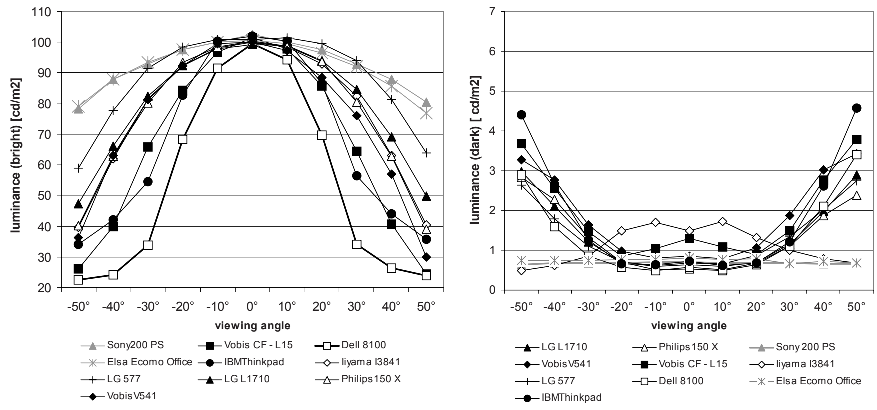

Fig. 41.3: Photometric measurements for different screen types. Left: luminance of bright areas (background). Right: luminance of dark areas (objects) (OETJEN & ZIEFLE 2009)

3 Anisotropy and Users' Age

In visual ergonomic studies dealing with LCD's anisotropy (e.g. GRÖGER et al. 2003; HOLLANDS et al. 2001, 2002; OETJEN & ZIEFLE 2004; OETJEN et al. 2005; ZIEFLE et al. 2003), mostly young adults have been examined as participants. However, young adults do not represent the whole working force which are using display technologies. Rather, children and teenagers as well as more and more older users do frequently use electronic displays within private and working contexts. Up to now, both major user groups have been mostly disregarded by visual ergonomic studies. As visual functions do significantly change with age (e.g. ELLEMBERG et al. 1999; KLINE & SCIALFA 1997; SALTHOUSE 1982), we need to know to what extent anisotropy affects performance in other age groups in order to maximize work productivity. Therefore, a first study is reported here in which teenagers, younger and older adults were compared with respect to visual performance in anisotropic displays.

3.1 Experimental Details, Procedure, and Design

Three independent variables were under study. (1) Screen technology: An LCD display (CF-L 15, 15", 1024 × 768) was compared to a cathode ray tube (CRT; Sony S 200 PS, 17", 100 Hz, 1024 × 768) which served as an experimental control condition. (2) Viewing angle: A 0° central sitting position was compared to a 50° extended sitting position. In the 50° off-axis position half the participants worked from the left and the other half from the right hand side. Five different viewing angles were established by virtually dividing the screen into three equally large sections (Fig. 41.4). For the central sitting position, two different viewing angles (0° and 11.3° on the left and right side of the screen) were extracted. In the 50° sitting position, three viewing angles resulted (41.4°, 50° and 56.4°). Performance was examined for these five viewing angles. (3) Users' age: In order to survey aging effects, three age groups were contrasted: a teenager group (28 participants, M=13.9, SD=3.3), a group of 28 young adults (M=23.9, SD=2.6) and an older age group (14 participants, M=56.4, SD=4.2). All groups consisted of 50% male and 50% female participants. Overall, 70 persons participated, all of them reported to be frequent computer users and accustomed to electronic reading. They had a normal or corrected to normal visual acuity and no history of eye-illnesses. The decimal visual acuity was at least 14/14 (Snellen) and it did not differ significantly between the groups (M_{10-18}=14/13, M_{20-31}=14/12, and M_{50-63}=14/13 Snellen).

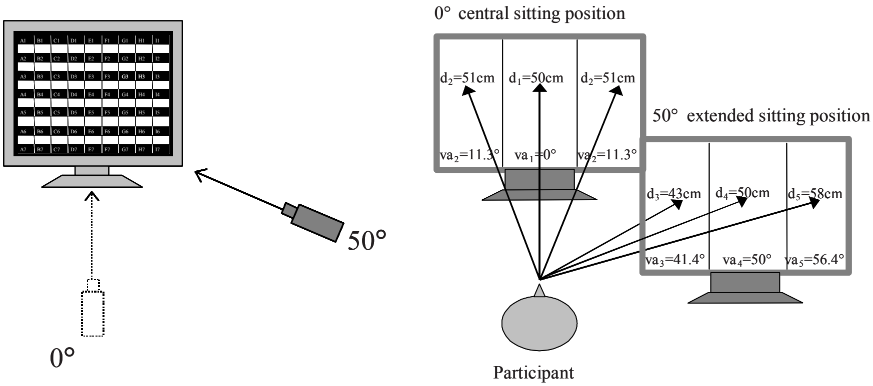

Fig. 41.4: Left: The photometer set up with the screen divided into 63 single fields; right: The experimental setting with the two sitting positions. By dividing the screen into three sections, five viewing angles can be distinguished (OETJEN & ZIEFLE 2007)

To measure the effects of these factors and to determine interactions, performance measures were used as dependent variables. (1) Speed (ms): The time participants needed to detect a target was recorded. (2) Errors: The accuracy of participants' reaction was measured.

As anisotropy is assumed to be primarily visual by nature, we used a simple detection task, which has a low cognitive complexity but is visually demanding. A detection task was used to quantify anisotropic effects on visual performance. Quadratic Landolt C's (with the gap oriented upwards, downwards, left and right) were displayed randomly on all 63 screen fields which had been measured within the photometric measuring procedure. Participants had to detect where the gap is and to indicate the chosen answer by pushing the appropriate button on a keyboard. Targets were eight pixels big (2.4 mm), the stroke width was one pixel (0.3 mm) and the gap was two pixels (0.6 mm). Participants had to push the central button of the keyboard and remain on this button until the encoding process was finished (discrimination time). As soon as participants detected the gap's direction, they had to release the central button. Instantly, the target disappeared and the appropriate answer key had to be pushed as quickly as possible.

As experimental design, a 2 (screen type) ×5 (viewing angle) ×3 (age) within/between experimental design was adopted. Screen type and viewing angle were treated as within group variables, user age as a between group variable. Four independent experimental conditions were applied: (1) LCD; sitting position of 0°, (2) LCD, sitting position of 50° off-axis, (3) CRT, sitting position of 0°, and (4) CRT, sitting position of 50° off-axis. In each condition 504 trials had to be completed. The order of conditions was counterbalanced across participants.

3.2 Results

Results were analysed by ANOVA-procedures. Levene tests were carried out to control homogeneity of variances, which was given for discrimination speed and accuracy. The significance level was set at 5%.

Overall, participants worked extremely accurately. For the whole group accuracy reached 98.1% (teenagers: 98%, young adults: 99.1%; older adults 96.5%). Neither age, nor screen technology or viewing angle revealed significant differences. With respect to the discrimination speed, significant effects were identified. A significant main effect of the screen type ($F_{(1,67)}=14.0$; $p<0.05$) was found: Over all screen positions, discrimination times were 7.6% longer for the LCD compared to the CRT. Another significant main effect was revealed for viewing angles ($F_{(4,268)}=82.2$; $p<0.05$): Discrimination times rose by 21.9% from the central (0°) to the 56.4° off-axis-conditions. Furthermore, a significant main effect of age ($F_{(2,67)}=9.4$; $p<0.05$) was identified: Young adults showed the fastest discrimination performance, and differed from the teenager group and the group of older adults, which did not show significant differences.

Performance decrements due to extended viewing angles were not equally disadvantageous for all groups (significant 2-way interactions of viewing angle and age; $F_{(8,268)}=14.5$; $p<0.05$): The largest performance decrease between the central and the off-axis viewing condition was present in the older group. Also, the significant 2-way interaction of screen type and viewing angle ($F_{(4,268)}=9.7$; $p<0.05$) shows that anisotropy is decreasing performance with increasing viewing angle more strongly in LCDs compared to CRTs.

The most crucial finding of the study however is the significant three-way interaction among screen type, viewing angle, and age ($F_{(8,268)}=2.9$; $p<0.05$). It shows that LCD's anisotropy does not equally disadvantage all age groups, but rather reveals to be age-related (Fig. 41.5). From Fig. 41.5 it can be seen that discrimination times decreased in all age groups when using an LCD instead of a CRT. Also, performance worsened when extended viewing angles were present. But the impact of anisotropy was most prominent in the older group, showing a tremendous performance decrease with increasing viewing angle.

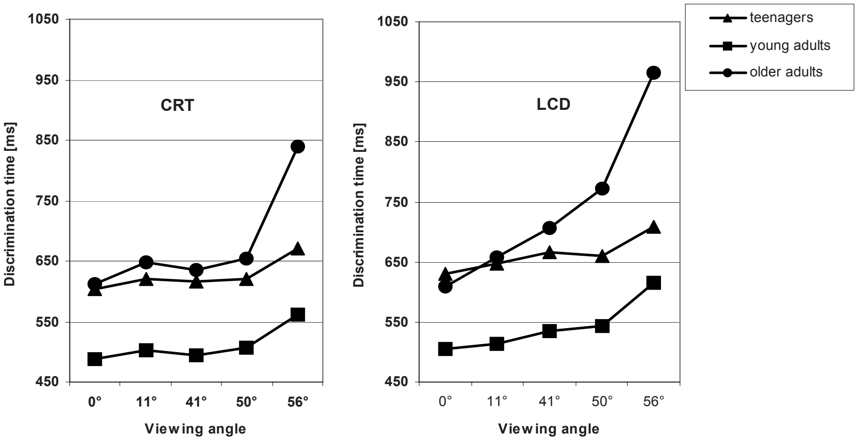

Fig. 41.5: 3-way interaction effect between screen type, viewing angle and age groups (OETJEN & ZIEFLE 2007)

4 Anisotropy in Notebook Computer Displays

In mobile contexts the probability of extended viewing angles is high especially when taking into account that mobile computers increasingly replace stationary desk top computer systems (KIRSCH 2004). Doubtless, it is definitively an advantage to work mobile and flexible, and we all do so. Though, the visual effects of electronic reading in notebooks should also be considered. The displays in notebooks have a lower threshold voltage than external LCD screens. This opens the possibility to use smaller components and reach an even lower weight. Further, energy consumption can be reduced and the operation time of the batteries can be extended, an important feature of computer notebooks. Lower threshold voltages can be realised as the liquid crystal mixtures in notebook-LCDs are slightly different from the ones used in conventional external LCDs (HECKMEIER et al. 2002). While visibility problems of LCD screens are well known by notebook users, whenever viewing angles are off-axis, up to now no research study was concerned with the visual effects of anisotropy in notebook devices. This was undertaken in the present study (OETJEN & ZIEFLE 2009).

4.1 Experimental Details, Procedure and Design

Two independent variables were under study. A first variable was the screen type (and the extent of anisotropy, respectively): (1) CRT; Elsa Ecomo Office; (2) LCD: CF-L 15 and (3) Notebook-LCD (Dell 8100). The second independent variable was the viewing angle: A central sitting position (0°) was contrasted to a 50°

off-axis position. Based on the two sitting positions five different viewing angles were extracted – following the same procedure as in the first study (Fig. 41.4). 30 young adults, 12 males and 18 females, volunteered (20–33 years; M=23.8). All had a normal or corrected to normal visual acuity (14/12 Snellen). Participants reported to be frequent computer users, and 57% of the participants were used to work with a CRT, the others used either an LCD or both screen types.

Dependent variables were the speed of visual performance (discrimination times in ms) and accuracy (errors). As experimental task, the same discrimination task as in the first study was used. Targets were quadratic Landolt C's with a gap at the top, the bottom, the right or the left. The target size was 1.5 mm in all screen types, the size of the gap 0.38 mm. Background luminance was set at 100 cd/m² in the centre of the screens; the targets had a luminance of 0.85 cd/m².

The study was based on a 3 (screen type) × 2 (sitting position)–experimental design with repeated measurement on both factors. Overall, six conditions resulted: (1) CRT with a sitting position of 0° (2) CRT with a sitting position of 50°, (3) LCD with a sitting position of 0°, (4) LCD with a sitting position of 50°, (5) Notebook-LCD with a sitting position of 0° and (6) Notebook-LCD with a sitting position of 50°. The order of conditions was balanced via a Latin Square. In each condition, 504 trials had to be completed.

4.2 Results

Discrimination times and accuracy were analysed by ANOVA procedures (repeated measurements). Assuring homogeneity of variance, Levene tests were carried out (it was given for both performance components). The significance level was set at p=0.05 (and adjusted in the case of multiple testing).

The screen type significantly affected discrimination performance in both discrimination speed ($F_{(2,58)}$=10.4; p=0.00) and accuracy ($F_{(2,58)}$=19.1; p=0.00). Thus, participants needed considerably more time to detect targets on the Notebook-LCD and had a lower accuracy than on the CRT and the external LCD. This is illustrated in Fig. 41.6.

Also, a significant main effect of viewing angle was found, for the speed of visual discrimination ($F_{(4,116)}$=59.7; p=0.00) as well as for the discrimination accuracy ($F_{(4,116)}$=28.2; p= 0.00). According to post-hoc-tests all single comparisons between the five viewing angles were significant.

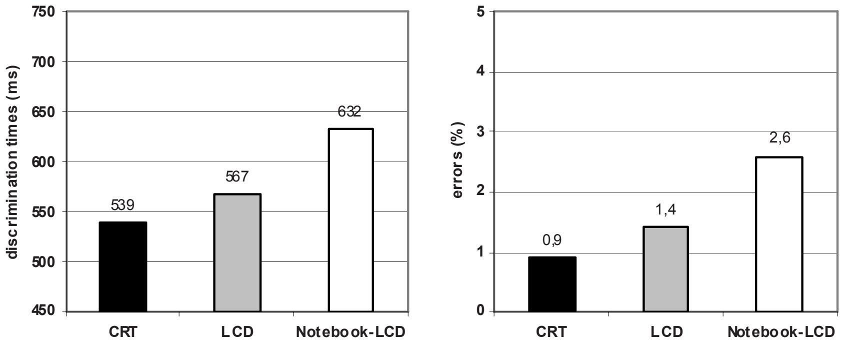

Fig. 41.6: Effects of screen types on discrimination speed (left) and accuracy (right) (OETJEN & ZIEFLE 2009)

The significant interacting effect between screen type and viewing angle is the most crucial finding (discrimination speed: $F_{(8,232)}=16.5$; $p=0.00$; discriminaion accuracy: $F_{(8,131)}=17.9$; $p=0.00$): Discrimination performance is distinctly worsening the more off-axis viewing angles were in the LCD conditions, especially in the notebook LCD (Fig. 41.7). Using a 50° sitting position increases the discrimination times far more when participants work with the Notebook-LCD than when an external LCD or a CRT is used.

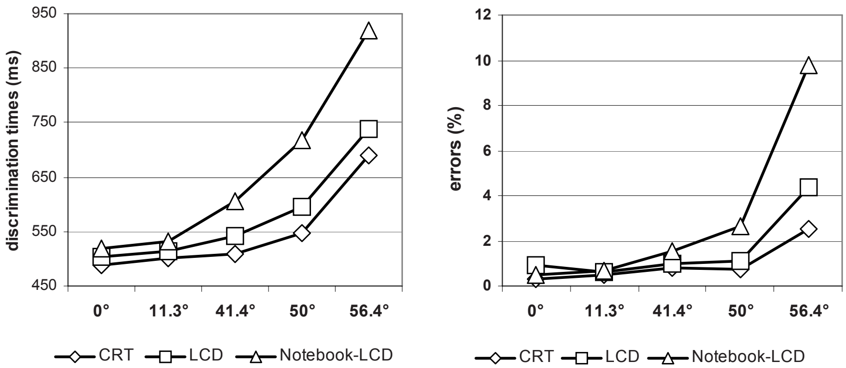

Fig. 41.7: Interaction effect of screen type and viewing angle on discrimination speed (left) and accuracy (right) (OETJEN & ZIEFLE 2009)

5 Discussion and Conclusion

The present chapter was concerned with the ergonomic evaluation of visual performance in electronic displaying of information, taking LCD's anisotropy in different screens into account. Though LCDs have many advantages, one of their major shortcoming is that luminance measures are not homogenous over the screen surface, but vary distinctly as a function of the viewing angle. In addition, users' age was under study, referring to the increasing user diversity which is present in the current work force. Most of the relevant research mainly used young adults as participants in visual ergonomic studies. Therefore, it was of considerable impact to learn which benefits but also barriers might be present in other user groups when using electronic displays. In accordance with recent studies (e.g. GRÖGER et al. 2003; HOLLANDS et al. 2002; OETJEN & ZIEFLE 2004; ZIEFLE et al. 2003), the present study corroborated anisotropy as a serious factor in LCD screens, especially in time-critical task settings. Physical measurements revealed the strongest fluctuation of luminance parameters for Notebook-LCDs, followed by external LCDs. The CRT technology was not affected by anisotropy.

When evaluating the aging impact, two prominent findings come into fore. One is that the effect of aging has to be taken seriously for computer work. As expected, young adults showed the highest performance level. The teenagers' group showed a considerable decrease in performance (23%). The performance decrement was still higher in the older group (33%). It should be noted here that outcomes might be a solid underestimation of the real situation, as the older group was comparatively young and not bothered by age-related visual illnesses. The second finding to be considered for human-centred work-place designs is that all age groups were negatively affected by anisotropy. Thus, having a "young" visual system does not defend screen users from anisotropy-based performance decrements. From an ergonomic point of view however it is especially meaningful that the older group turned out to be affected strongest by anisotropy. This should be taken into account in work settings for older adults.

When focussing on the screen types and levels of anisotropy, it can be concluded that Notebook-LCD performed worst. Over all screen positions, the mean performance difference was 6% when CRT and external LCD were compared, and it increased to 18% between CRT and Notebook-LCD. The strong susceptibility to off-axis viewing can be demonstrated, when only the off-axis conditions are contrasted. In the 56.4°-condition the speed of visual discrimination decreased by 33% in the Notebook-LCD compared to the CRT. Though, it has to be considered that the major advantage of Notebook computers is the possibility to work in mobile settings, and this advantage is not taken into account in this research. Also, it should be mentioned that for privacy reasons anisotropy effects might be welcome. With respect to their visual display quality, however, Notebook computers do not lead to the best visual performance possible.

Concluding this research, recommendations for screen types should be related to the task context they are to be used for and tailored to the specific user group which is using these displays. When taking visual ergonomic issues in discrimination tasks into account, considerable performance decrements have to be expected when LCDs are used, time-critical tasks have to be completed, the whole display surface is used to display the stimuli and/or extended viewing angles are present.

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42 Forty Years of Research on System Response Times – What Did We Learn from It?

Wolfram Boucsein

1 Setting the Stage Before the Mid 1980s

With the advent of time sharing computer systems in the late 1960s, temporal factors came into the focus of human-computer interaction (HCI). To the present author's knowledge, NICKERSON et al. (1968) and CARBONELL, et al. (1968) were the first authors to point to the psychological importance of involuntary delays in HCI. They concluded that computer-system originated waiting times should either be rather short, thus preventing the work flow from being interrupted, or be long enough to allow for the so-called job swapping which means executing another task during the waiting period.

On the background of communication theory, a similar point was made by MILLER (1968), who recommended upper limits of 2 seconds for intratask- and 15 seconds for intertask-computer elicited waiting times to prevent a breakdown during the HCI dialogue. Otherwise, the human operator should be allowed to behave as a time-sharing system, switching to other tasks during the interruption. These early insights are still valid and more recently discussed as determining optimal system response times (BOUCSEIN 2000) and under the concept of multi-tasking (SCHAEFER et al. 2000).

The term "system response time" (SRT) was introduced by WILLIGES and WILLIGES (1982) and SHNEIDERMAN (1984) who divided the human operator's behavior in alternating "operant" and "respondent" parts. These terms – taken from psychological learning theory – were used to classify actions during HCI depending on who initiates them: the human (operant) or the computer (respondent). The time between the termination of the user's input and the computer's "prompt" was labeled SRT.

System response times are of particular importance for HCI because of their stress inducing properties (for a summary, see BOUCSEIN 2000). Without providing empirical data, PETERS (1977) pointed to observations of an increased heart rate (HR) during waiting times in HCI. MARTIN (1973) did not only focus on the

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length but also on the variability of SRTs, the latter supposedly being a source of uncertainty and thus possibly stress inducing. His recommendation, though also not empirically backed up, was that the standard deviation should not exceed half of the mean SRT. In addition, Martin pointed to the importance of task complexity for the tolerability of SRTs. This had been already pointed out by SACKMAN (1970) who reported that operators became rather impatient if SRTs for simple tasks exceeded 10 seconds and/or were irregular, whereas if an operator assumed that the computer was currently busy with handling a huge amount of data, SRTs up to 10 minutes could be well tolerated. Cognitive psychologists later called this the "model which an operator has from the computer" (SHNEIDERMAN 1984).

2 Psychophysiological Stress-Inducing Properties of System Response Times

Based on psychological stress theories, BOUCSEIN et al. (1984) set the stage for a comprehensive research program on the possible stress inducing properties of mean duration and variability of SRTs, based on the following two general hypotheses:

(1) Any increase of mean SRTs beyond a well tolerated time span will induce stress by means of anticipating negative consequences such as overtime work or salary reduction (GREIF 1983). This hypothesis was probed using SRTs of different lengths.

(2) A continuous work flow which is interrupted by intervals of unpredictable length is likely to produce uncertainty, which is also a source of psychological stress (MONAT et al. 1972). This hypothesis was probed using SRTs of different variability.

Since stress induced by SRTs could be expected to show up instantaneously, measures of the autonomic nervous system would be the adequate psychophysiological responses to look for (BOUCSEIN 1988, 2006, LUCZAK 1987). Taking samples of hormones such as catecholamines and cortisol would be more suitable for determining long lasting phenomena such as the inability to unwind after work (MELIN & LUNDBERG 1997).

Between 1982 and 1997, the present author's group performed a series of systematic laboratory studies on the stress inducing properties of SRTs. Similar to the type of assessment of HCI chosen by CARD et al. (1983), a rather simple computer task was chosen to permit a close control of task variables in relation to SRTs. A space surrounded by identical letters had to be targeted within a line of otherwise randomly generated letters and spaces, which was presented in the center of a visual display. Only two studies (THUM et al. 1995, SCHAEFER & KOHLISCH 1995) used a more complicated task to individually standardize mental strain. In our studies, SRTs were varied systematically between 0.5 and 8 seconds. Additional time pressure was induced by using incentives for working as fast and as correctly as possible or by announcing overtime work in the case of incorrect solutions.

As autonomic nervous system measures, we applied skin conductance level (SCL), frequency and mean amplitude of nonspecific electrodermal responses (NS.EDRs), systolic and diastolic blood pressure (SBP and DBP), mean arterial BP, HR, heart rate variability (HRV), and respiration rate. In addition, frontalis electromyogram (EMG) was recorded as another indicator of short lasting stress responses. As performance measures, we used task completion time, numbers and relevance of keystrokes, cursor movements and errors, whereas ratings of mood and bodily symptoms were applied as subjective measures.

Table 42.1. Results from six studies on System Response Times: a: SCHAEFER et al. (1986), N= 20; b: KUHMANN et al. (1987), N= 68; c: KUHMANN (1989), N= 48; d: KUHMANN et al. (1990), N= 24; e: THUM et al. (1995), N= 40; f: KOHLISCH & KUHMANN (1997), N= 42. EDR freq. = EDR frequency; EDR amp. = EDR amplitude. (after BOUCSEIN (2000), Table 14.1)

SRT	Parameter category	Incentive (time pressure) present	Incentive (time pressure) absent
	physio-logical	SBP [b, e], mean arterial BP [f] and/or DBP [e] increased HRV decreased [e] Respiration rate increased [e] EMG frontalis power increased [e] NS.EDR freq. increased [f]	SBP and DBP increased [a] HR increased [d]
short (0.5 – 2 sec)	behavioral	Error rate increased [b, e, f] Number of cursor movements [b], working speed [e] and irrelevant keystrokes [f] increased	Error rate increased [a, d] Working speed increased [d]
	subjective	More headache and eye-related symptoms reported [b]	General arousal increased [d] Number of task related symptoms increased [a]
	physio-logical	SCL increased [b] NS.EDR freq. increased [b] NS.EDR amp. increased [e] SBP and DBP decreased [e] Respiration rate decreased [e]	Increasing amount of EDA during SRT [c] NS.EDR freq. initially increased but decreased later [d]
long (8 sec or longer)	behavioral	Error rate low [b, e]	Error rate low [a, d] Number of cursor movements increased [c] Task completion time prolonged [c]
	subjective	Negative motivation and emotion increased [e] More symptoms of headache reported [f]	General well being enhanced at the beginning of work [c]

2.1 Effects of SRT Duration and the Concept of an Optimal SRT

Our results from six laboratory experiments with altogether 242 subjects are summarized in Table 42.1 (taken from BOUCSEIN 2000, Table 14.1). Contrary to our hypotheses, our general findings were that negative physiological, behavioral, and subjective consequences resulted not only from rather long but also from rather short SRTs. If in case of the latter, incentives for working fast such as time pressure were present (top of the third column of Table 42.1), our subjects developed considerable cardiorespiratory strain, i.e., increases of SBP, DBP, and respiration rate, plus a decrease in HRV. In addition, there was an increase of EMG frontalis activity and of NS.EDR frequency (NS.EDR freq.). The subjects showed an increase in error rate, cursor movements, and irrelevant keystrokes as signs of impaired performance. They also reported more subjective complaints which are typical for computer workplaces. When no time pressure was imposed on the subjects under the short SRT conditions (top of the fourth column of Table 42.1), physiological and subjective effects were less computer-task specific, and only rather slight increases in SBP, DBP, and HR were observed. However, there was an increase of general subjective arousal and the number of task-related bodily symptoms. Despite not being instructed to do so, our subjects spontaneously increased their working speed, the consequence of which was an increase of error rates. Since our subjects were not experienced computer users, our impression was that they may have felt rushed by the tasks being presented too fast for their personal tempo.

When SRTs were rather long, a different picture emerged. At first glance, it looked as if rather long SRTs simply resulted in a more relaxed and careful work style, compared to the case when incentives for working fast were present, e.g., time pressure (bottom of the third column of Table 42.1). Subjects made fewer errors, presumably because error correction was much more time consuming. However, any increased relaxation was perceived rather than real, because subjects experienced their working situation as uncomfortable, which is shown by an increasing number of negative emotions and headache symptoms. In addition, an increase in SCL, NS.EDR frequency, or mean NS.EDR amplitude suggested an augmentation of emotional strain. Results without incentives, e.g., without time pressure (bottom of the fourth column of Table 42.1) were similar with respect to a low error rate. However, subjects used their resources less effectively, increasing the number of cursor movements and the time needed for task completion. Furthermore, an enhanced subjective well-being, which had been reported at the beginning, faded during the course of work. At the same time, emotional tension developed as indicated by an increasing amount of EDA during SRTs with duration of 8 seconds (KUHMANN 1989). The decrease in EDA after an initial increase reported by KUHMANN et al. (1990) corresponds to an application of SRTs within a single task instead of SRTs between tasks. In general, effects of long SRTs on

EDA are more pronounced under time pressure, compared to conditions with no incentives for working fast.

We consider an increase of workload due to high work density a possible reason for the stress-inducing effects of short SRTs, which is in accordance with elevated cardiorespiratory activity (top of the third and fourth columns of Table 42.1). However, since increased cardiorespiratory activity can be regarded as an indicator for physical strain (BOUCSEIN 1993), it should be ruled out that our results were mediated by an increased amount of physical activity required under short SRTs, whereas long SRTs might have imposed less motor activity on our subjects. This was probed by varying motor demands and mental load as independent factors in two experiments performed by KOHLISCH & SCHAEFER (1996). The task used in the first study was to use compensatory keystrokes for keeping a cursor moving towards the left margin of the screen within a target area in the middle of the screen. They experimentally varied the required motor activity in four steps by manipulating the cursor speed, using inter-keystroke intervals of 150, 300, 600, or 1,200 milliseconds, respectively. Mental load was varied by narrowing or widening the target area, thus changing the required accuracy for keystroke synchronization. A completely balanced within-subjects design was applied, in which 24 subjects performed a training of 20 seconds and a test trial of 90 seconds for each combination of conditions. Besides mean inter-keystroke intervals, they recorded heart period (instead of HR) and NS.EDR freq. as psychophysiological measures. When the mean inter-keystroke intervals were 300 milliseconds or longer, cardiovascular and electrodermal measures remained unaffected by motor activity which is in accordance with CARRIERO'S (1975) finding that tapping below 333 milliseconds does not exert considerable influence cardiovascular and electrodermal variables. A second study with 42 subjects confirmed this result. In this experiment, an additional arithmetic task was applied for the induction of mental load. Again, no significant effects of motor activity on psychophysiological variables were found below 360 milliseconds. In HCI, the reported range for mean inter-keystroke intervals lies between 891 milliseconds and 5.01 seconds (RAUTERBERG 1992), with a mean of 453 milliseconds for data entry tasks (HENNING et al. 1989). Because the intervals had been as high as 880 milliseconds in the KUHMANN et al. (1987) study, an increased motor demand cannot account for the psychophysiological changes observed under short SRTs. Therefore, an increased mental workload under short SRTs is the most likely explanation for the observed cardiorespiratory stress effects.

To further probe the importance of mental workload for psychophysiological effects of SRTs, THUM et al. (1995) performed a study with 40 subjects. They kept metabolic demands due to mental workload constant while varying SRTs, by using an adaptive computer task developed earlier by KUHMANN (1979). This task consisted of a randomly generated 6 × 6 matrices of 36 two-digit numbers where the subjects had to decide whether one, both, or none of the two target numbers were present. An algorithm continuously varied the presentation time of the matrices, becoming shorter after a correct response and longer after two subsequent mistakes, thereby ensuring that all subjects achieved the same percentage of correct responses. After each single task, feedback was given to the subject. The first of three 7-minute trials was performed with 1.5 seconds SRTs, the two others with 0.5 seconds and 4.5 seconds in a counterbalanced order. Half of the subjects were given monetary incentive for exceeding a certain performance level. HR, SBP, DBP, respiration rate, EDA, and frontalis EMG were recorded, and after each trial, task features (e.g., difficulty in comparison with a reference trial) as well as emotional states during the task were rated. Compared to the medium SRT of 1.5 seconds, both short (0.5 seconds) and long (4.5 seconds) SRTs significantly increased HRV while HR was reduced. In addition, short SRTs increased DBP, while long SRTs increased NS.EDR amplitude and reduced SBP and respiration rate. Compared to 0.5 seconds, the 4.5 seconds SRTs increased the NS.EDR amplitude and the HRV, but reduced SBP, DBP, and respiration rate. This complex outcome of the THUM et al. (1995) study shows that SRTs being shorter and longer than a certain medium range may induce considerable psychophysiological strain. Therefore, effects of short SRTs on HR and HRV as displayed in the upper part of Table 42.1 may be due to mental workload since they no longer appear when this factor is controlled.

The adverse effects of rather short SRTs determined by our research group have been challenged by SCHLEIFER and OKOGBAA (1990). In their own experiment, 45 female professional typists performed an alphanumerical data entry task in response to a series of prompts displayed on a VDT screen on 4 consecutive days. Their subjects worked either under short and invariable (350 ms) or long and variable (3–10 seconds) SRTs. Half of their subjects received a monetary incentive for working faster and a penalty for making more errors compared to an individual baseline. Results indicated that time pressure imposed by monetary incentives led to increased cardiovascular strain (increased SBP and DBP, decreased HRV) during the last 2 days of their experiment. However, no significant effects of SRTs and no interactions between SRT and incentive conditions were found in their psychophysiological measures. One possible explanation could be the difference in subjects between our studies and the Schleifer and Okogbaa one: Their typists may have been acquainted with the combination of short SRTs and monetary incentives, which was not the case for the student subjects used by our group. Additionally, there was no chance for the adverse effects of long SRTs found by our group in electrodermal measures, since Schleifer and Okogbaa restricted themselves to cardiovascular measures.

Provided that various psychophysiological studies have shown detrimental effects of very short SRTs, the general recommendation "faster is better" (see the title of a paper by SMITH 1983) does not seem to be appropriate for HCI, except for programmers (LAMBERT 1984). Instead, our results support a concept of an optimal SRT, which is in accordance with the notion of SHNEIDERMAN (1992, p. 277) that there is a preferred SRT for a given user and task, and that both shorter and longer SRTs may generate debilitating effects on the effectiveness of HCI. Based on the research performed by our group, our recommendation in the mid

1990s was to determine an optimal SRT for each task in question. The criteria for such an optimal SRT were considered:

- no marked increases in cardiovascular activity,
- low NS.EDR freq.,
- no increased general muscle tension,
- best performance, and
- lowest reports of pain symptoms.

With the particular task and kinds of subjects used by our group, the optimal SRT turned out to be 5–6 seconds (KUHMANN 1989). Presumably, the optimum would be shorter for experienced computer users who are familiar with the task, such as the typists used by SCHLEIFER and OKOGBAA (1990), but also for other kinds of tasks (e.g., about 1.5 seconds for the task used by THUM et al. 1995). Optimal SRTs could well be much longer, as was the case in the BARBER and LUCAS (1983) study, where the optimal SRT was 12 seconds for establishing telephone circuits in interstate networks.

KOHLISCH and KUHMANN (1997) exemplified how such an optimal SRT for the task in question should be determined. Their 42 subjects performed the detection task, as applied by our group so far, for 10 minutes under three conditions in a balance repeated measurement design. SRTs were either 1 second (i.e., short), 5 seconds (i.e., medium), or 9 seconds (i.e., long). An extra amount of unpaid overtime work was announced if the subjects' performance would not meet a combined speed-accuracy criterion checked by the computer. This was introduced to provide an incentive for working as fast and correct as possible. Besides recording speed and accuracy, HR, BP and EDA as well as subjective ratings of mood, arousal and bodily symptoms were obtained. As a result, the percentage of errors, the amount of irrelevant keystrokes and mean arterial BP were significantly increased under short SRTs compared to the other two conditions. Unexpectedly from the results summarized in Table 42.1, NS.EDR freq. was significantly higher under the short, compared to the long SRT condition. The authors concluded that the 1-second SRT was stress and error inducing. Since the amount of subjectively reported headache was significantly higher under SRTs of 9 seconds compared to those of 5 seconds, KOHLISCH and KUHMANN (1997) considered 5 seconds as an optimal SRT for the specific combination of task and subjects.

Attempts to theoretically explain the adverse effects of prolonged SRTs date back to MILLER's (1968) review on response times in HCI. Based on communication theory, Miller considered a breakdown of the human computer dialogue a possible cause for stress-inducing properties of rather long SRTs. As a consequence, he recommended an upper limit of 2 seconds for intra-task and 15 seconds for inter-task SRTs. Another possible explanation is that computer users may become concerned with prolonged SRTs since the penalty for errors increases because of slowing down their work (SHNEIDERMAN 1992). In addition, prolonged SRTs have been found detrimental for the user's motivation and work satisfaction (e.g., SCHLEIFER & AMICK 1989, THUM et al. 1995, TREURNIET et al. 1985). Both may in turn contribute to performance decrements.

2.2 Effects of Variability of SRTs and Reducing Their Stress-Inducing Effects

Since temporal uncertainty may also be an important stress inducing factor in HCI (BOUCSEIN et al. 1984), it has been suggested that not only the length but also the variability of SRTs may induce strain by a mechanism of inducing uncertainty concerning the temporal course of HCI (CARBONELL et al. 1968). Unexpectedly, no dramatic effects were found when considerable SRT variability was introduced (see SHNEIDERMAN, 1992, Chap. 7.6, for a summary). For example, in two studies that introduced zero or 80% variability of SRTs as a second experimental factor besides 2 and 8 seconds SRT duration, neither significant main effects of variability nor interactions with duration were found (KUHMANN et al. 1987, SCHAEFER et al. 1986). To resolve this issue, another study was performed by SCHAEFER (1990) with 48 subjects. After 20 minutes training with 1 seconds SRTs for all subjects, four independent groups performed the detection task used earlier by our group with 2, 4, 6, or 8 seconds fixed SRTs for another 20 minutes. The following six blocks of 20 minutes each used a so-called stop-reaction time procedure. This means a sequence of events presented with constant intervals is halted from time to time. The subjects' task is to press a key as soon as they notice such an unpredictable event. Subjects were instructed that system breakdowns would occur in irregular sequence instead of the ordinary SRTs, and that a "restart key" would enable them to continue their work. To prevent subjects from speeding up their work by pressing this key, the restart needed 8 seconds. As a result, no significant effects of SRTs on HR, or SBP and DBP were found. The plot of mean stop-reaction times against SRTs fitted a positively accelerated power function with an exponent of 3.39. An alternative linear model had to be rejected, apparently due to the marked increase of stop-reaction times under the 8 seconds SRT condition. Similar results were obtained for the standard deviations of the stop-reaction times. This points to a deterioration of temporal sensitivity for SRTs with durations between 6 and 8 seconds, since means and standard deviations of stop-reaction times were in agreement with Weber's Law up to 6 seconds but no more with 8 seconds SRTs. An impaired predictability resulted in performance decrement under the 8 seconds SRT condition, where subjects needed more time to complete their tasks because more cursor movements were performed. As a consequence, the failure of our earlier studies to determine a separate effect of SRT variability was re-interpreted insofar, as temporal uncertainty could have been the critical factor for the adverse effects not only of the variable but also the constant 8 seconds SRT condition. The reason is that subjects may have not been able to subjectively distinguish between those conditions.

To address the question, how predictability of SRT duration influences the working behavior, KUHMANN and SCHAEFER (2007) conducted a study with 50 subjects who performed the error detection task used earlier by our group. The target to be identified and marked with the cursor could occur in 10 different positions. SRTs were either coupled with the target position and thus predictable, or randomly distributed, thus making SRTs unpredictable. In another condition with predictable SRTs, the part of the text line on the left side of the target remained visible on the screen during SRT, thus indicating its actual duration. In 20% of the tasks, presenting the subsequent task was delayed until the subjects pressed a "restart key" as in the stop-reaction time procedure introduced by SCHAEFER (1990). However, pressing the "restart key" before the SRT was expired resulted in an unproportional long additional waiting time, which considerably prolonged the working time. Because of the importance of correctly estimating the SRT in this setting, the stop-reaction task consisted a vehicle to access the subjects' internal representation of SRTs. Results showed that stop-reaction times under the predictable condition corresponded to the target positions of the preceding task, while they were uncorrelated with the previous target positions in the unpredictable condition and often exceeded the longest SRT. Both strategies, differential responding and responding to the longest SRT, indicate that subjects tried to optimize their total amount of working time. However, differential responding which occurred under the predictable condition was associated with additional cognitive work load compared to the unpredictable condition. The KUHMANN and SCHAEFER (2007) results strongly support the use of displaying the actual progress of the computational task in case of unpredictably variable SRTs, instead of giving an estimate for the time until task completion as used in most PC based software systems. However, in case of predictable SRTs, it is advised not to indicate elapsed or still to be expected parts of actual SRTs, since users are able to detect regularly interspersed SRTs by implicit learning and optimize their work flow according to the system's temporal behavior.

The observable detrimental effects of unpredictable SRTs during mental tasks may be partly due to the fact that SRTs are normally used for preparing a subsequent work step. Therefore, SRTs can be confusing if their anticipated duration does not correspond to their actual duration. In general, it will be more likely for preparatory-related problems to appear in inter-task SRTs than in intra-task SRTs. Therefore, an intra-task SRT paradigm was used by SCHAEFER and KOHLISCH (1995) to determine the kind of mental processes during SRTs by means of EEG recordings from Fz and Pz. Their 54 subjects performed a series of 360 target recognition tasks which served as a model for database retrieval. After presentation of an artificial target word on the screen, SRTs of 1, 2, or 4 seconds were imposed on one third of the subjects each, prior to the appearance of a recognition list. The match of SRTs with the subjects' expectation was varied as an additional within-subjects factor as follows: The standard SRT was reduced by 25% in 30 trials and increased by 25% in another 30 trials, which were randomly interspersed between standard trials. For each condition, latencies and amplitudes of N100 and

P300 following SRT termination were obtained. The N100 and P300 latencies were larger and recognition time was longer when SRTs were unexpectedly short, whereas P300 amplitudes were increased and working speed was reduced for the subsequent task when SRTs were unexpectedly long. In addition to the demonstration of distortions during information processing, this result stresses the importance of a stable and predictable SRT in HCI.

Intra-task SRTs were also probed by KUHMANN et al. (1990), using 24 subjects, who worked on a modification of the detection task used earlier by our group. Two rows of random letters with spaces as used in the other studies were combined into one task, after which the subjects had to report whether a target (i.e., a space surrounded by two identical letters) was detected or not in either of the subsequently presented lines. After 15 minutes training with constant 1 second intra-task SRT between the two lines, subjects performed four 10 minutes trials in a counterbalanced order with intra-task SRTs of 2 or 8 seconds, crossed with zero or 80% variability as a second factor. Again, SRT variability did not have any effect on physiological and performance measures, but there was significantly less subjective well being and more symptoms of general excitement in variable compared to constant SRTs. In accordance with the results from inter-task SRTs, cardiovascular activity (i.e., HR) was increased while working under short intra-task SRTs. However, an increase in NS.EDR freq. observed under long SRTs at the beginning reversed during the course of the trials. In accordance with our hypothesis that detrimental effects of SRTs would show up if they were introduced within a task, SRTs mainly affected performance in the second part of the task. Under short SRTs, subjects worked significantly faster on the second line but their error rate increased as well. Performance decrements and physiological as well as subjective strain are likely to occur not only when SRTs exceed a certain optimal range but also when SRTs are too short for the task in question. This has been found for both, intra-task SRTs and inter-task SRTs.

In accordance with our second general hypothesis, HOLLING and GEDIGA (1987) formalized a theoretical approach based on the cognitive stress theory of Lazarus (MONAT et al. 1972), using a probability model for determining the course of strain development during SRTs. According to a proposal made by CARBONELL et al. (1968), they assumed a linear non-decreasing function for psychological costs, e.g., the amount of anger associated with SRT duration. The subjective expectation of SRTs was regarded as a probability distribution. As a result, the integrated conditional expectation of the future costs allowed for a precise prediction of the time course for developing strain during the actual SRT.

To analyze the predictions of the model, Holling and Gediga performed a laboratory study with 72 subjects who worked for 6 trials of 12 minutes each on the simple detection task used by our group. Four experimental conditions made up from 2 or 8 seconds mean SRT duration crossed by constant or variable SRTs were applied in a counterbalanced order. Heart rate and BP were recorded, and ratings of subjective stress, weariness and anger were obtained after each trial. Their results supported the strain increasing property of SRT variability and stated that 8 seconds SRTs were more stress-inducing than those of only 2 seconds duration. However, the assumption of a linear cost function had little predictive power for the course of strain developing during SRTs.

A possibility for the reduction of stress induced by long and/or unpredictable SRTs may be providing feedback on the status of the task in progress. In a laboratory study with 48 subjects whose task was to correct errors detected by the computer in seven files consisting of 100 forms each, HOLLING (1993) applied two versions of the task already used by HOLLING and GEDIGA (1987) in a counterbalanced order. One version gave no information about the status of the task, while the other one continuously displayed the number of the form which was actually being checked by the computer. Standardized differences between the measure of strain, developed by HOLLING and GEDIGA (1987) under both conditions were computed for EDA (SCL) and HR. Stress detected by EDA was significantly lower when feedback was given, paralleled by a decrease in subjective strain measures of anger and arousal, whereas feedback did not exert a significant effect on HR.

Besides using indicators as feedback for the progress of an actual SRT, their stress-inducing properties may be reduced by allowing the user to behave like a time sharing system – a suggestion made as early as by MILLER (1968). In a preliminary study performed by SCHAEFER et al. (2000), 48 students worked on a mocked power plant control center setup. A panel showed 36 displays to be set to particular initial values, some of which were to be requested from a virtual remote data bank by transmission lines. During the processing times for these requests, which were 10 seconds for half of the subjects and 30 seconds for the other half, the setup procedure could be either continued or additional requests could be started. As an additional within-subjects factor, feedback on the progress of opened requests was either not provided or given as a static or a dynamic display. EDA, ECG, peripheral blood volume and respiration were continuously recorded, and keystrokes and request handling were written in log-files. Subjective ratings were taken after each feedback condition. Results showed that the multi-tasking features were more often used when the processing times were long, a condition under which subjects also reported more arousal and pain symptoms. For short processing times, both frequency and amplitudes of NS.EDRs significantly increased, indicating increased emotional strain. Cardiovascular measures did not yield significant effects. These results mean that the psychophysiological patterns seems to be reversed compared to the former results of our group with single-task systems. We concluded that under multi-tasking conditions, long SRTs seem to be more convenient since they may be used for the performance of other work steps, which is not the case with short SRTs. It is also a possibility that EDA may have indicated the inappropriateness of using multi-tasking procedures during too short processing times.

An additional resource for coping with stress-strain processes induced by SRTs may be using the multi-tasking capabilities of modern computer systems. Instead of merely waiting for the computer to respond, the user may decide to work on several processes simultaneously. However, if SRTs do not exceed a certain duration, the benefit from switching to another task instead of waiting may be more than outweighed by the additional mental load that results from scheduling (the term scheduling refers to the need for organizing the work flow of different tasks running in parallel). Maintaining an optimal scheduling is an additional mental challenge for the user and thus becomes another source of stress. Coping with this type of stress can be facilitated by providing appropriate feedback on the temporal aspects of processes running in the background while a main task is performed. Therefore, process indicators play an important role in multi-tasking systems.

The aim of the next two studies (BOUCSEIN et al. 1998) was to establish the relationship between the duration of SRTs (i.e., the duration of processes running in the background), the type of feedback given by process indicators, and the stress-reducing properties of multi-tasking. We expected the stress-reducing features of multi-tasking to become more prominent with increasing background process duration. Furthermore, we expected the stress imposed by the need for scheduling to be reduced if the temporal flow of processes running in the background is visualized by means of process indicators. Two types of process indicators were applied: a static and a dynamic-relative indicator. In order to create a realistic environment for multi-tasking, a simulated computer aided design (CAD) task was programmed permitting two different background processes. The task consisted of a series of three pages with 12 screws, each of which was to be calculated and inserted. Users were asked to get a screw symbol with the mouse from a graphic board, insert it at the predetermined position and measure the required length by using two mouse clicks. Background process 1 was started by entering the numbers for thickness of material and required strength for the screw in a separate window. The results of this process were the minimal length and diameter required for the screw. Those numbers were entered in another window for background process 2 that resulted in the norm length and diameter of the screw fitting for the particular purpose. Finally, the numbers for length and diameter were entered in a window in order to generate the selected screw, and the screw was draught to its place with the mouse.

A first study with 18 male engineering students was performed to determine the minimal background process duration for a successful multi-tasking. Three different values for the process duration (10, 20 and 40 seconds) were applied in counterbalanced order. Electrodermal activity, HR, EMG recorded from the neck, BP, respiration rate, and electrooculogram were continuously recorded, together with different working strategy parameters such as mouse movements, processes in use and activity breaks. Subjective ratings were taken after each CAD page. Covariance analyses were applied after eliminating general habituation effects over trials. Psychophysiological parameters did not yield significant effects, presumably because of the different work strategies used during the three different levels of processing times as could be shown by strategy parameters. Besides causing longer working periods, prolongation of background process duration times resulted in less arousal and more emotional strain. The highest error rate and the strongest self-rated bodily pain symptoms occurred with processing times of 20 seconds. Our conclusion was that the 20 seconds background process duration might have the most benefit from introducing process indicators.

As a consequence, the background process duration of 20 seconds was used in a second study with 42 male engineering students. Three different experimental conditions were applied in counterbalanced order: A process indicator (an hour-glass showing up until the background process was done), a dynamic-relative process indicator (a horizontal bar filling from left to right proportional to percent-done of the background process), and no process indicator as a control condition. We expected the dynamic indicator to further reduce mental strain, but possibly increase emotional strain because of its property to push towards the end of the task in progress. Psychophysiological, subjective, and performance measures as well as the statistical evaluation were the same as in the first study. The presence of process indicators accelerated working speed and cardiorespiratory activity, regardless of the indicator type. The rate of utilization of the multi-tasking features increased significantly with the presence of process indicators: In only 53% of the time there was no background process active as compared to 56% under the no-process-indicator condition. This rate of utilization difference was better reflected in subprocess 1 than in subprocess 2 where the significance was only marginal. However, only in less than 2% of the time both subprocesses were simultaneously activated. The only physiological measures affected by the introduction of process indicators were the systolic blood pressure and the respiration rate, both increasing significantly. In the subjective domain, anxiety/depression decreased slightly but significantly. On the other hand, there was a marginal significant decrease in subjective well being with increasing complexity of the process indicators. The psychophysiological changes observed can be easily explained with the increase in performance.

In general, there were not many differences between physiological measures under the different experimental conditions in both studies. Instead, we observed marked differences in various measures of working strategy. Our interpretation is that our subjects had so many degrees of freedom in the CAD task that they were able to compensate for both kinds of possible stress inducing factors (mental and emotional) by changing their working strategies accordingly. In our former work on system response times, we used highly determined task sequences with almost no degrees of freedom. Therefore, the present results do not directly compare since the CAD task used allowed for multiple degrees of freedom. Those may be used as an additional resource for preventing stress caused by adverse factors in the work flow such as forced waiting periods. The introduction of process indicators increased working speed and accordingly cardiorespiratory activity. However, there is no increase in neck muscle tension and no stress relevant change in electrodermal or subjective measures. Instead, subjective anxiety and depression show a small though significant decrease.

We concluded that using multi-tasking computer systems may increase the amount of work and enhance performance but does not seem to increase psychophysiological stress. Moreover, the kind of process indicator used does not really matter, although the presence of such indicators shows superiority over the absence of process indicators. It is concluded that multi-tasking may facilitate action regulation as an additional resource for coping with psychophysiological stress during HCI.

3 System Response Times – A Persisting Problem

Despite the comprehensive research program that our group has performed and published for more than 15 years (with an extension to recently), the computer software engineering community almost completely disregarded the results from psychophysiological research on SRTs. In the field of designing interfaces, results from the so-called cognitive psychology still prevail, focusing on time estimation and perception, attention memory, and user rated satisfaction (e.g., SHNEIDERMAN & PLAISANT 2005). There are, however, a few exceptions.

HÜTTNER et al. (1995) stated that SRTs no longer contain a problem with stand-alone personal computers, however, are still of great relevance in case of access to a central unit within a network. A very common mistake in designing such systems is to minimize SRTs as much as possible. A much better strategy would be to avoid SRTs becoming too variable (the standard deviation should be less than half of the mean), and to provide a preliminary instantaneous response to inform the user about the processing being started. Especially when SRTs exceed 30 seconds, an analog indicator of the system progress is required to avoid adverse effects. However, analog indicators that do not really correspond to the time to be elapsed as seen in various Windows-based applications can not be trusted and will hence be prone to again produce adverse effects.

With the advent of the World Wide Web, SRTs became everyone's "daily bread". As a consequence, the issue of possible detrimental effects of SRTs on the course of HCI and its outcome gained some importance for the design process of interfaces (JACKO et al. 2000). Since SRTs consist an unavoidable by-product of interactions between multiple users – as they already did for multiple terminals connected to a single mainframe in the late 1960 – one does not have to be a prophet to predict that SRTs will continue to be a significant issue in designing interfaces for any kind of HCI (POLKOSKY & LEWIS 2002).

In a study with 26 subjects, grouped into skilled and unskilled Web users, TRIMMEL et al. (2003) found an increase of psychophysiological strain with prolonged SRTs. Their subjects performed three Web tasks with 2, 10 and 22 seconds SRT duration. Regardless of their level of experience, subjects who rated their subjective stress level being heightened emerged higher HRs compared to those with a lower subjective stress level, and their HRs increased with the duration of SRTs. The authors concluded that uncertainty about the outcome of the S's last action could be seen as a main source of an increase in psychophysiological strain. Hence, SRTs persist as an important source of stress in the world of Web.

Since speed has been considered one of the most important issues for Web users, interfaces that come with long and/or unpredictable SRTs may have both serious psychological and economical consequences (LIGHTNER et al. 1996). Even short SRTs of no more than 2 seconds may exert detrimental effects on the conversational nature of HCI (MILLER 1968). Delays of 8 seconds are commonly regarded as a threshold for adverse psychophysiological and performance consequences (BOUCSEIN 2007, SHNEIDERMAN & PLAISANT 2005). In addition, SRTs of 8 seconds and more may have a similar uncertainty-eliciting effect as variable SRTs (SCHAEFER 1990), thus inducing stress and feelings of anxiety, in particular with respect to the possibility of the occurrence of HCI breakdowns (BOUCSEIN et al. 1984).

Improving computer speed is not always a proper solution to prevent adverse effects of SRT; it may even have contrary effects (see Table 42.1). As a consequence of improving the page load speed from 8 to 2–5 seconds, long SRTs brought about reduced levels of trust and caused a lot of traffic as users sought alternatives (NIELSEN, 2000). This may not only lead to a decrease in user dissatisfaction but also to considerable losses in e-commerce sales, since Web users may simply give up trying to buy an item if they feel messed about by long and/or unpredictable SRTs.

Since making computer systems and networks faster will provide no general solution for the nagging problem of SRTs, software engineers should focus on how to mitigate their adverse effects. Based on our research as summarized in Sect. 2, the following measures could be considered:

- Fostering multi-tasking during which the user may be encouraged to behave like a time-sharing system (SCHAEFER et al. 2000), combined with
- providing indicators for elapsed time instead of imprecise estimated time until task completion (KUHMANN & SCHAEFER 2007).

Such a venture can not be successfully performed without empirical studies which include psychophysiological measures (BOUCSEIN et al. 1998). Otherwise, stress-inducing properties of interfaces for HCI may be left undetected, making the whole designing process unfeasible.

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43 Productivity Improvement with Snap-Fit Systems

Kurt Landau, Uwe Landau, Hamed Salmanzadeh

1 Introduction

The use of plastic attachments in the automotive industry is increasing steadily. Snap-fits now account for more than 20% of attachment systems used in motor vehicle assembly (HÜBNER et al. 2006) and a shift from screw fastenings to snap-fits has been evident for several years now. Snap-fits have significant cost benefits over screws (STUMPP 2007). For example, integral construction methods reduce the number of assembly operations and make it possible to cover joints (e.g. in the cladding of vehicle interiors).

Snap-fits also cut manufacturing time by facilitating pre-assembly of modules where work objects are more readily accessible to the operator. Pre-assembly of vehicle components generally helps to reduce worker stress, because it can be performed under anthropometrically more favorable working conditions. Other snap-fit benefits include time-saving and, in most cases, reduction in component weight. On the downside, they can cause handling problems and may be less amenable to recycling.

Although work with snap-fits can cause extremely high strains on the skin and joints of workers, who frequently have to perform several thousand snap-fit motions per shift, there has to date been very little investigation of its effects on skin, wrist joints, tendons etc. Sharp-edged snap-fits can cause skin irritation and considerable force often has to be exerted with the fingers when making the connection. The biomechanical consequences of these extreme forces for the joints involved in this type of operation are being investigated (LANDAU 2008a, SALMANZADEH 2008).

This contribution does not, however, address the ergonomic aspects of snap-fit attachment work. Please refer to LANDAU (2008b) and SALMANZADEH (2008) for findings on this aspect. In the authors' opinion, there are serious research deficits in the product and industrial engineering of snap-fits, and they have therefore concentrated in this publication on the effects of snap-fit design on operating time requirements for performing these positioning operations under mass assembly conditions.

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The designer of a snap-fit should endeavor to anticipate the attachment's effect on productivity during *the early design phase* (SANZENBACHER 1993).

Our investigations were confined solely to processes involving MTM components (BOKRANZ & LANDAU 2006).

2 Current Research Status

2.1 Definitions

A snap-fit is a form-locking fastening linking two components and using no other positioning feature than the intrinsic elasticity of the materials. The resistance of a projection, which is briefly deflected before springing back into its original position, has to be overcome during the positioning procedure.

Various parameters can be used to classify snap-fits, for example, the type of design elements used to perform various functions. These are essentially the fastening and positioning elements. Snap-fits consist of a block fitted with hooks (locks) and guides (locators and enhancements; Fig. 43.1).

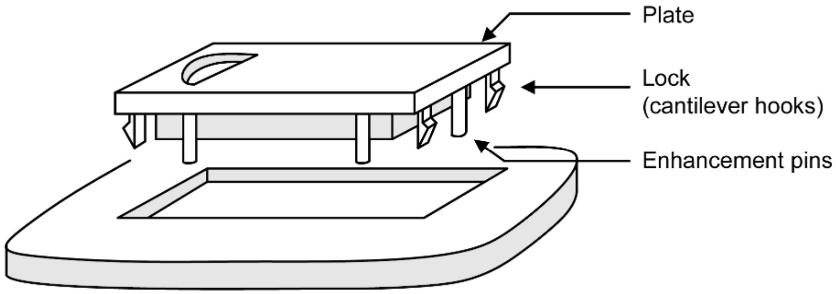

Fig. 43.1: Features of a snap-fit

The hooks are frequently designed on the bending beam principle, but other solutions are also possible.

In order to be safe in use, a snap-fit must meet four basic design criteria (BONENBERGER 2005):

- Strength: a property of the material used, enabling it to withstand the stresses to which it is exposed after assembly. A snap-fit not possessing the necessary strength will fail in use.
- Constraint: a function of the locking features, enabling them to form a stable fastening. A snap-fit can create a lock in all 12 degrees of freedom, while at the same time permitting controlled relative movements.
- Compatibility: which means that hooks and lugs must be designed so that neither the positioning nor the dismantling operation is hindered by the snap-fit's functional elements.

- Robustness: ability to withstand all variable and unexpected influences during development, manufacture, assembly and use. For example, to be rated as robust for assembly purposes, a snap-fit must incorporate auxiliary features preventing assembly error. It must also have locators to facilitate centering and locking in.

Aside from certain special designs, snap-fit attachments can be (a) laid on or (b) hinged in before being pressed down or in (Fig. 43.4). There are also (c) systems using press and twist motions. In case (a), finger orientation, fastening motion and locking of the snap-fit are a unit. In cases (b) and (c), finger orientation, positioning and locking are separate. Feedback of success of the snap-fit operation is obtained by random sampling using tactile and/or auditory controls.

2.2 Productivity

BOOTHROYD and DEWHURST (1983) and POLI et al. (1986) have published estimates of the time required for handling and assembly of snap-fit systems according to the shape of the object, locking strength, number of steps in locking operation, need for alignment etc. A series of publications by GENC et al. (1998a,b) and MESSLER et al. (1998) systematizes the design procedures for snap-fit features. These refer to both specific methods of design and general design procedures, e.g. PAHL et al. (2003). SURI AND LUSCHER (2000) have defined existing design parameters, such as strength and cohesion, and identified new ones, like volume- and dimension-related cohesion, locking ratio, characteristic dimensions etc, and discussed the use of individual parameters to optimize topology of snap-fit fastenings against functional, ergonomic and other criteria.

MTM-1 (DMTM n.d.) is an extremely high-definition process building block system that provides the snap-fit designer with a *planning analysis* showing the effects of his design decisions on handling and positioning times when the snap-fit is introduced into mass-production operations. It is, however, not yet clear whether MTM-1

- makes due allowance for all snap-fit design features,
- is able to produce valid forecasts of the actual time required by a worker for completion of the snap-fit operation (this contribution does not address other aspects of the test theory, e.g. differences in rating reliability between individual MTM analysts).

MTM-UAS (Universal Analyzing System; DMTM 2000) is an updated version with an "Assembly" section containing analyses of specific snap-fit operations. The drawback of UAS is its high degree of aggregation, which makes its analyses unsuitable for evaluation of design decisions.

Critical reviews of *ergonomic* work system design of MTM building block systems, e.g. STRASSER (1996), have been published. Although parts of the debate on this subject are relevant to snap-fit attachment systems, the present article ignores ergonomic considerations and criticisms of MTM, because its aim is to focus solely on timing and performance aspects.

LUCZAK and GÖBEL (1996) investigated psycho-physical aspects of sensorimotor activities based on MTM-1 process building blocks. Their investigation demonstrates clearly that, although it is possible to identify the key factors influencing positioning time with components that are difficult to position and where the engage direction is crucial, the influence of accuracy of fit is very small in this case. PAHL et al. (2003), ANDREASEN et al. (1985) and BÜRGER (n.d.) define systematic procedures for design of positioning operations that are suitable for use in mass-production assembly. Although individual aspects of these can be applied to snap-fit attachments, it is not possible to use them for quantitative statements on productivity.

It is clear from review of the current state of research that

- the relationship between snap-fit design features and productivity at serial manufacturing level has not yet been adequately investigated,
- the degree to which MTM-1 process building block systems are applicable to all features of snap-fit attachments is not known,
- no procedural guidelines for designers are available.

The findings described below attempt to eliminate at least some of these deficits.

3 Methodology

An empirical analysis of the snap-fit systems manufactured by Raymond Group and used by an automotive manufacturer was performed. The results were used to prepare a taxonomy (Fig. 43.2). This taxonomy enabled us to select the following forms as particularly relevant for productivity investigations:

- plugs
- strips
- attachment systems using screw bolts.

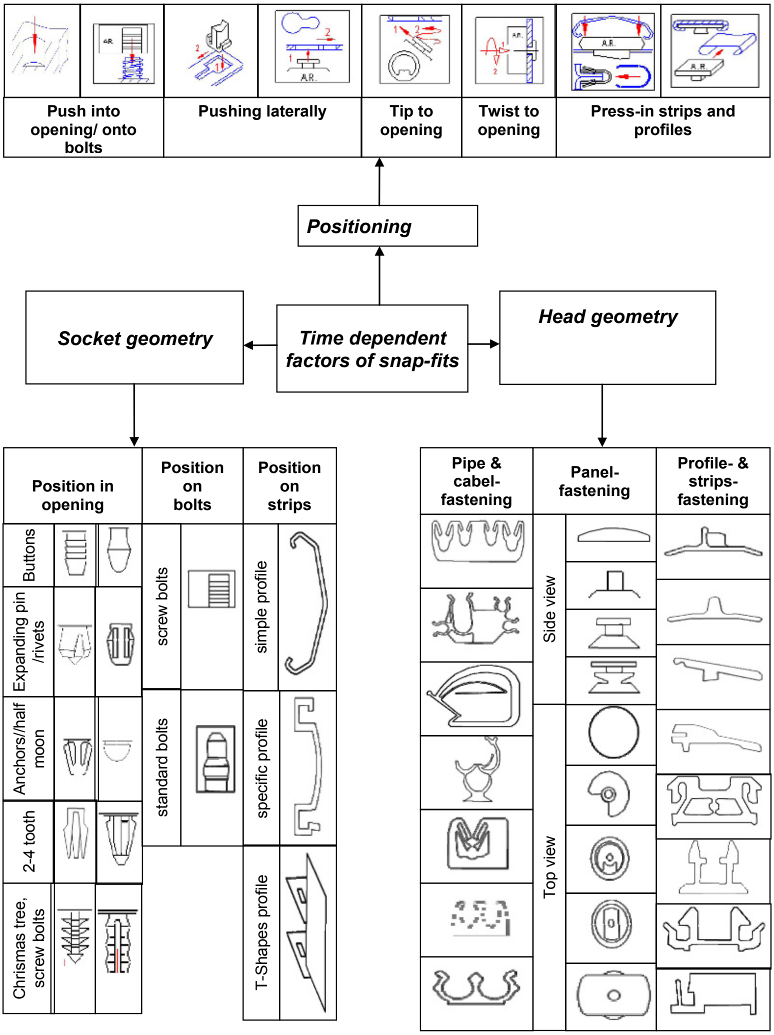

Fig. 43.2: Taxonomy of productivity aspects of snap-fit systems

Lack of space and poor visibility of work objects are two factors influencing motion paths and motion acceleration. Centering is facilitated if the snap-fits have enhancements or chamfers. The snap-fit's design symmetry determines the number of micro-motions prior to positioning. The actual positioning and, consequently, the time involved in this are influenced by the snap-fit's dimensions, shape, material characteristics, surface and graspability. The number of positioning steps (either consecutive or simultaneous, e.g. mating, engaging and locking) and the forces exerted for these influence assembly time. If allowance is made for the large number of positioning operations performed over a full shift, fatigue effects must also be factored in.

As it seems possible that MTM-1 may be unable to make due allowance for all the factors listed above, we have included practical MTM-1 analyses for 33 different snap-fit designs in the motions affecting productivity. The MTM-1 studies of these 33 snap-fit designs were based on the following premises:

- the work is performed in a sedentary position at an assembly table
- the snap-fits are lying in open receptacles on the assembly table
- receptacles and positioning point are 50 cm from the worker.

Working conditions specific to certain snap-fit types (e.g. press-on decorative strips L = 2000 mm), were recorded directly in the MTM-1 analysis. A sedentary working position was chosen because this eliminated the need to make allowance for other effects, such as standing/walking, impediments arising in conveyor belt assembly etc (BOKRANZ & LANDAU 2006).

The analyst performing the MTM-1 analysis had 20 years of experience in the use of MTM, primarily in the automotive industry. The results of the analysis were listed in a league table of positioning time data, initially for three types of snap-fit attachment systems – plugs, strips and screw bolts. The inter-relations of snap-fit properties, basic MTM factors and supplementary MTM-1 factors were then computed on a four-stage scale (Table 43.1). Time factors were then calculated (Table 43.2).

4 Results

4.1 League Table of MTM Timings

4.1.1 Plugs

Figure 43.3 shows the league table of MTM timings for 16 types of plug widely used in the automotive industry.

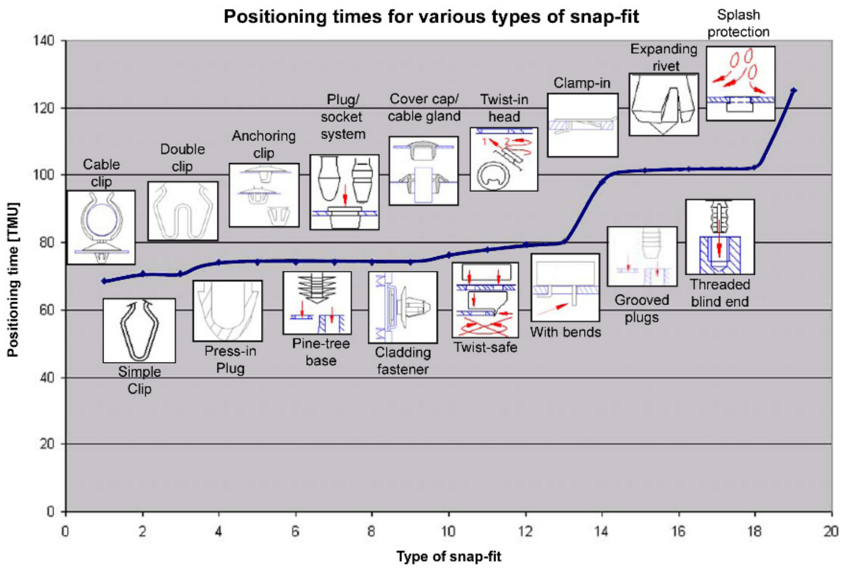

Fig. 43.3: Positioning times for various types of snap-fit attachment (1 TMU = 0.036 seconds)

Lineal pressure motions using plugs with a conical foot yield short positioning times. Pine-tree feet, the need for a combination of positioning motions and special designs (e.g. splash-protected attachment systems) require longer positioning times.

In many cases a combined positioning operation involving both pressing and sliding takes up to 40% more time than a simple pressing movement to insert a plug. (Fig. 43.4).

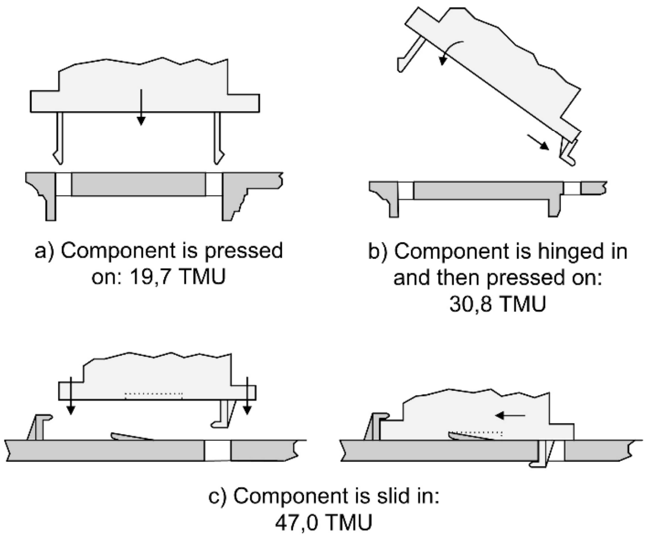

Fig. 43.4: Comparison of positioning times for pressing in, hinging in and pressing, and sliding in (1 TMU = 0.036 seconds)

The rigidity of the base part affects the positioning operation. If this is thin sheet metal or sheet metal backed by several centimeters of filler material that give during the positioning process, this can cause canting of the mating part. In such cases, the positioning operation sometimes requires exertion of high forces that give rise to extremely high hand-arm strains (Cf. Landau 2008b). MTM-1 makes allowance for factors such as base parts of unstable metal sheet by classifying them as “more complex to perform”. This raises the timing of the operation by 5.6 TMU by reclassifying the snap-fit from P2SE (16.2 TMU) to P2SD (21.8 TMU).

4.1.2 Strips

Decorative strips that only have to slid onto a base profile (the left part of the curve in Fig. 43.5) have a shorter positioning time than strips that have to be pressed on. The operation of pressing on at several points (with the hand functioning as tool) and the need to adjust the strip to make it flush with the base part increase positioning times (right part of curve in Fig. 43.5).

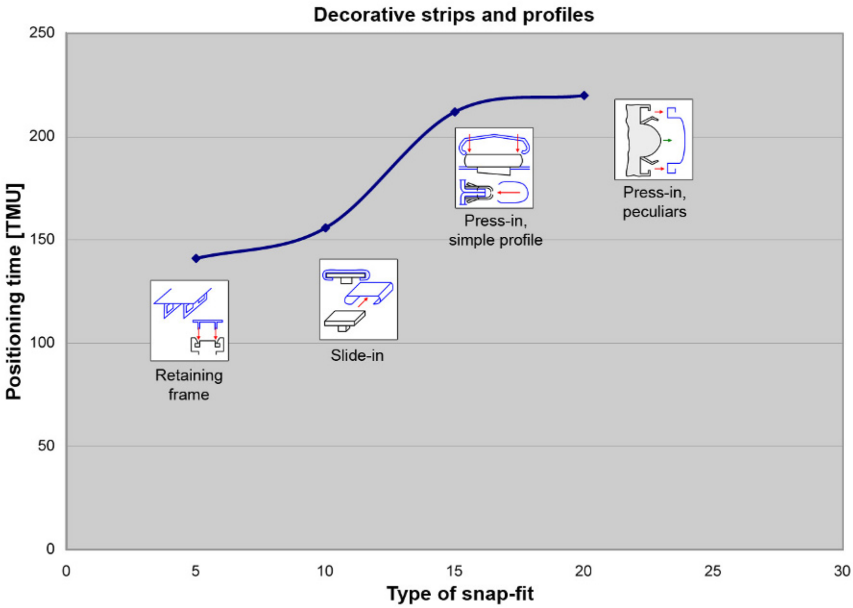

Fig. 43.5: Positioning times for selected strips and profiles (1 TMU = 0.036 seconds)

4.1.3 Attachment Systems with Screw Bolts

Simple pressing-on of screw bolts is the operation requiring the shortest positioning time (Fig. 43.6). In cases where strong pressure is required, the attachment system is recoded from P2SE (5.6 TMU) to P3SE (43 TMU). There are similar increases in positioning times for operations involving twisting-in with a force > 1 daN (see middle section of curve in Fig. 43.6). In cases where a snap-fit has to be screwed tight after insertion into the base part, this can, for example, involve the following series of MTM codes: P2SD/M2B/RL1/R2A/G1A/M2B, which raise the TMU to 65.8. This effectively nullifies the timing advantages anticipated from the use of a snap-fit attachment system. If the situation is aggravated by stiffness of the bolt/nut system, positioning times rise to the levels reached in the upper parts of the curve.

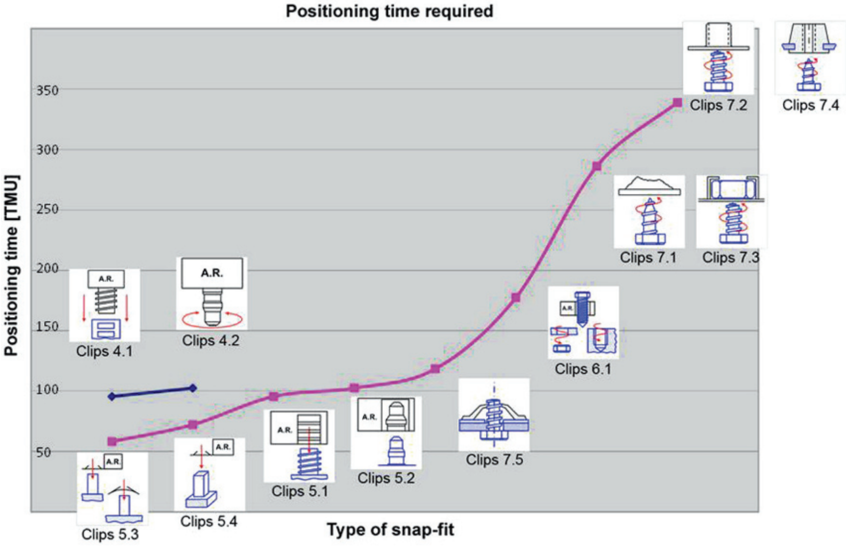

Fig. 43.6: Positioning times for snap-fits with screw bolts (1 TMU = 0.036 seconds)

4.2 Snap-Fit Features and MTM-1 Factors Influencing Their Use

Two experienced MTM analysts made independent ratings of the most important features of the snap-fit attachments investigated in the study against MTM-1 criteria. Table 43.1 shows that snap-fit features ranging from dimensions to design of functional elements affect at least one of the six MTM-1 factors. The gray-shaded fields show the features for which the MTM factors make no allowance. This indicates that MTM-1 covers the essential features of snap-fit attachments.

Table 43.1: Snap-fit features and their effect on basic and supplementary MTM-1 factors

		MTM-1					
		Basic factors			Supplementary factors		
Snap-fit features		Fit	Symmetry	Handling	Pressing	Twisting	Additional motion
Dimensions	(3D)	0	3	3	0	0	0
Positioning force	(2 N - 250 N); allowance made for tightness of fit	3	0	3	3	0	0
Positioning motion	Pushing	3	0	3	3	0	0
	Sliding	2,5	3	3	3		2
	Tipping	2,5	3	3	3	0	0
	Twisting	2,5	2,5	3	3	3	0
Work method	One-handed	3	3	3	0	0	0
	Two-handed	3	3	3	0	0	0
Surface	Flat, easy to grasp	0	1,5	3	0	0	0
	Sharp-edged	2	0	3	0	0	0
	Other adverse features (e.g. oily, wet)	0	0	3	0	0	0
Type of grasp	Direct contact (e.g. with fingertips)	3	0	3	3	0	0
	Pinch grip (e.g. with tweezers)	0	0	3	0	0	0
	Power grip	0	0	3	0	0	0
Functional elements	Tight-closing	3	3	3	3	0	0
	Snap-fits with enhancements	3	2	3	0	0	0
	Other (e.g. large-scale radii or chamfers)	3	2,5	3	0	0	0

Key: 0 not applicable, 1 minor significance, 2 certain aspects, but not of overall significance, 3 good, fully significant

The effects of the features of each snap-fit attachment on positioning time were also recorded. Table 43.2 demonstrates the extent to which design features of various types of snap-fit attachment affect job-timing. In operations involving pressing-on of plugs, for example, to close holes in vehicle bodies, nearly all of the design features, but especially the snap-fit's surface characteristics and functional elements, have major effects on time required.

In cases where snap-fits are glued in, it is only possible to evaluate the push motion, but its influence on timing is very strong.

In operations involving positioning of (decorative) strips, the pressing and/or sliding motions, the surface characteristics and, of course, the work method (one-handed or two-handed) all affect job-timing.

Table 43.2: Snap-fit features and their effect on positioning times

Snap-fit features		Type of snap-fit: Plug – Push	Plug – Drive in	Plug – Glue	Strip – Slide in	Strip – Press in	Special profile
Dimensions	(3D)	3	3	3	3	3	3
Positioning force	(2 N - 250 N); allowance made for tightness of fit	3	3	3	3	3	3
Positioning motion	Pushing	3	1	3	3	3	3
	Sliding	2	0	0	3	1	1
	Tipping	2	0	0	0	0	0
	Twisting	2	0	0	0	0	0
Work method	One-handed	3	1	3	3	3	3
	Two-handed	3	1	3	3	3	3
Surface	Flat, easy to grasp	3	3	3	2	2	2
	Sharp-edged	3	3	3	3	3	3
	Other adverse features (e.g. oily, wet)	3	3	3	2	2	2
Type of grasp	Direct contact (e.g. with fingertips)	3	3	3	1	2	2
	Pinch grip, (e.g. with tweezers)	3	3	3	3	3	3
	Power grip	2	2	1	3	2	3
Functional elements	Tight-closing	3	3	3	1	1	1
	Snap fits with enhancements	3	3	3	0	0	0
	Other (e.g. large-scale radii or chamfers)	3	3	3	0	0	0

Influence on timing
Key: 0 not applicable, 1 minor influence, 2 moderate influence, 3 major influence

5 Discussion and Conclusion

Snap-fit geometry and positioning kinematics that result from it have significant effects on positioning times required in serial assembly operations. For example, combined motions (such as pressing-on followed by sliding-in) involve a perceptible delay between the initial pressing-on and the subsequent sliding-in or locking-in (e.g. a coding of P2SSE + M2A).

From the data summarized above it is possible to make the following design recommendations relating solely to productivity aspects and ignoring ergonomic considerations:

- Forces required for positioning should be reduced, e.g. by allowing a degree of play instead of using tight press-on snap-fits.
- In operations involving positioning of long strips the workplace should give the worker sufficient room to make the attachment without hindrance.
- Surfaces should be flat and easy to grasp.
- Work with sharp-edged, oily or wet snap-fits should be avoided.
- Snap-fits should have adequately dimensioned, chamfered enhancements.
- Special designs of snap-fits should be avoided wherever possible, because their use generally involves relatively long positioning times.

MTM-1 only makes a single allowance for more difficult working conditions by classifying an item as “more complex to handle”, even in cases where combinations of such conditions arise during a positioning operation. No allowance at all is made for additional stresses, such as, for example, unfavorable hand position. Allowance is made in the fit category (loose, firm or tight) for the forces exerted during the positioning process. But it is not possible to make any general differentiation between “firm” and “tight”.

From the job design point of view, it is advisable to plan for use of suitable tools or even to seek mechanized or automated options in all cases where snap-fit attachments are used either repetitively or in large quantities.

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44 Developing Seating Designs that Support Traditional Japanese Sitting Postures

Kageyu Noro

1 Seating Comfort in Asian Traditional Ways of Seating

Zen sitting is an Eastern way of sitting. Buddha first introduced this *lotus position* circa 500 BC. The *lotus sitting style* differs from traditional Yoga sitting postures and is characterized by symmetrical positioning of the left foot over the right thigh, and the right foot over the left thigh.

Zen sitting is only one of many Eastern sitting postures cited by HEWES (1957). As Buddhism spread from India across the East, the influence of sitting style expanded across Asia.

The great Master Dogen founded Zazen Buddhism in the 13th century and introduced the *Zafu posture* to promote postural stability. For this reason, Zen monks in Japan now commonly assume Zafu while meditating (Fig. 44.1) *Zafus* are now also used in Western countries (*s.f.* www.dharma.net).

The Zafu sitting style is in marked contrast with those in the West. While Zafu sitting promote postural stability, Western chair designs aim to facilitate changes of posture. Placing a Zafu underneath one's buttocks facilitates deep breathing (Deep breathing is characterized by a protruded abdomen, upright spine and expanded diaphragm.) and lengthens the spine by raising the gluteus maximus around the sacrum and thereby inducing forward pelvic rotation. In contrast, Western seats commonly attempt to induce pelvic tilt through lumbar supports. This suggests backrests are not necessary to achieve pelvic tilt in the seated position.

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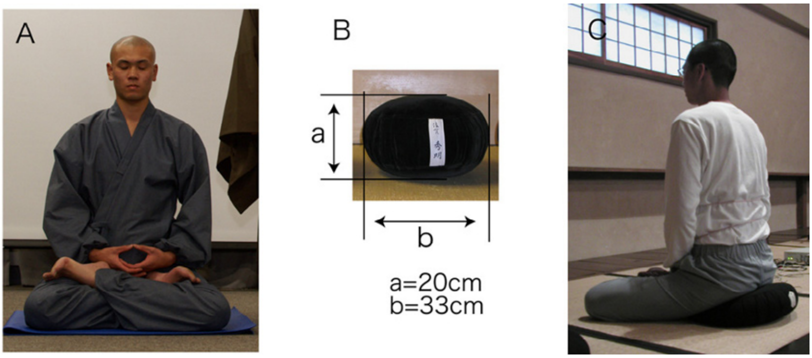

Fig. 44.1: Zen sitting and Zafu.
A: Zen sitting (front);
B: Typical zafu dimensions in Japan;
C: Zen sitting (rear view)

Figure 44.2 compares pelvic rotation (Pelvic tilt was measured using a patented device (JAPAN PATENT OFFICE CERTIFICATE 2007) invented by the author that detects three-dimensional changes in pelvic position (illustration is from WU et al, 1998, Fig. 44.3.) associated with these postures: standing, Zen sitting, floor sitting, kneeling (*seiza*) and sitting crossed-legged (*agura*) and on a chair. Measured angles are referenced to standing positions; positive values represent a forward pelvis rotation while negative values signify backward rotation relative to standing. Findings indicate that the Zen sitting position induced a superior pelvic tilt to all positions other than standing.

Fig. 44.2: Comparison of pelvic rotation

Most people in the East now find it difficult to assume Zen cross-legged full-lotus positions due to the popularization of seated kneeling, *seiza,* in the Edo era (1603–1867 A.D.). By the 1980s, some even began to perform Zen sitting in chairs in place of *zafus*.

Even so, Zen sitting and chair sitting have to some extent co-existed since ancient times. For example, see two sculptures excavated in India in the fifth century and now preserved at the British Museum. These include: (1) Sculpture of Zen sitting: The preaching Buddha, Khera, Central India, Gupta period, 5th century AD (the British Museum) (2) Sculpture of chair sitting: The preaching Buddha, seated in European posture Sarnath, Central India, Gupta period, 5th century AD (the British Museum). Several historical records also demonstrate that chairs were in use in Japan since around the 10th century. There is a description in Taiheiki (Taiheiki is one of the masterpieces in Japanese classical literature, considered a Japanese historical document) referring to Eastern-style round-backed armchairs (*Kyokuroku*) in the story of March 5, 1366 (YASUDA 2008). Those chairs were most likely introduced from the Yuan Dynasty (1279–1368 A.D.) of China. Various types of chairs have been used to a limited extent among the royalty and aristocracy in Japan since the 10th century, as cited in Engishiki (Engishiki is an ancient code law compiled in the Heian era, 794–1185 A.D.), up to this day (JINGUJI-CHO 1970).

NORO (2005) used a participatory approach to develop a chair for *Zazen* sitting (This SotoZen project was launched in 2003 at Waseda University. A follow-up conference is described at www.humanics-es.com/zenseating.htm) that would accommodate Zen priests, who maintained a desire for specialized Zazen seating that might induce serenity by supporting neutral postures that promote a sense of free-float necessary to attain their desired spiritual state of nothingness. Unfortunately, no such chair is currently available in the market. This paper describes experimental research directed towards developing such a chair.

2 Theoretical Aspects and Development of Seating Comfort

In Eastern countries, floor seating has been adopted since ancient times, while in the West, chair sitting has long been central to daily life. Distinctions between Eastern floor seating and Western chair sitting are described below.

2.1 Western Theories

NORO et al. (2006) summarized historical trends in Western perspectives on seating that evolved as an outgrowth of the findings of KEEGAN (1964) and proposed an alternative Eastern perspective. Keegan (It should be pointed out that Keegan's research, though brilliant and historically pivotal, would have been considered quite limited today as it considered of repeated X-rays of a single young male lying on a horizontal surface) focused on discussions about pathological problems caused by flexion of the lumbar spine associated with seated postures. He also proposed design criteria to promote lumbar lordosis.

2.2 Seating Comfort Required for Zen Sitting and a Chair Design Theory: An Eastern Theory

Ergonomists involved in Eastern floor seating (including Zazen), place a greater emphasis on muscle physiology (*esp.* hips, buttocks and thighs) than did Keegan. This is attributed to the traditional lack of backrests for floor seating, including *zabutons* (floor cushions) and *zafus*. Since floor seating requires less area to sustain body weight (smaller footprints) compared with chairs, greater emphasis is placed on the seatpan and its associated seating comfort. Not surprisingly, there is far less research on this topic than on Western sitting.

2.2.1 Three Essential Ideas Underlie Eastern Theory

(1) Promote forward pelvic rotation through seatpan design.

WU et al. (1998) pointed out the significance of sustaining areas adjacent to the sacrum for upright sitting, rather than lumbar supports, which exert horizontal forces on the lumbar spine from backrest.

(2) Maintain appropriate pressures on the buttocks (NORO et al. 2005).

Figure 44.3 shows experimental results of the seat pressure distributions on seat pans that provide sacral support (A of Fig. 44.4).

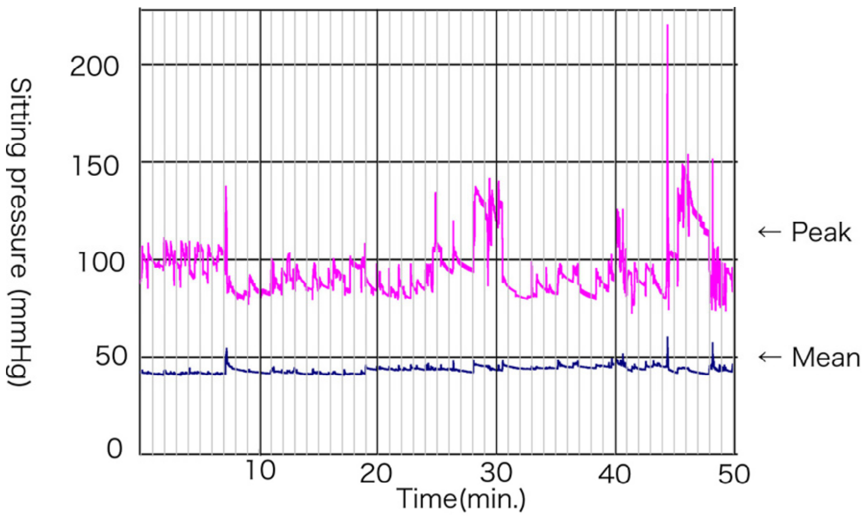

Fig. 44.3: Mean and peak values of sitting pressure on seatpan over 50 minute trials.
***Subject*:** a female weighing 63 kg.
Task: reading,
Chair: 3D seatpan upholstered with a thin cushion (as shown in A of Fig. 44.4)
Measurement conducted at Gifu Pref. Human Life Technology Research Institute

The experiment measured changes in seat pressure distributions with subjects sitting upright over 50-minute seating trials. Peak values obtained are plotted on Fig. 44.3. In this figure, peak values averaged about 100 mmHg, with increased magnitude of fluctuation after 25 minutes. This suggests that increases in sitting pressures causes the sitter to shift positions more frequently as their discomfort increases. This is why reseating leads to a decrease in peak levels of sitting pressures.

(3) Distribute seated pressures.

The function of chairs is to sustain human body weight while buttock and thigh muscles support sitting. The greater the area of support (and seat pressure distributions), the less the corresponding load is experienced by its users.

The primary objective of this study is to further investigate the relationship between sitting comfort and seat pressure distributions (surface contact rather than point-contact). Since buttocks are convex, concave shapes distribute seat pressures more effectively on the seatpan.

Yet buttocks and thighs have quite different seat comfort characteristics. KISHI (2005) described the displacement of seated buttocks and thighs as a function of load deformation (push-in-hardness) and other relevant parts of the seated body.

To further evaluate the impact of posture on users' comfort, we analyzed the correlation between seated displacement of the buttocks and thighs with users' subjective ratings of comfort. A negative correlation was found between buttock displacement and comfort, with no correlation between thigh displacement and comfort.

Using a neuroscientific approach, NORO et al. (2006) indicated that seated pressure distributions that reduce seat pressures on muscles around the buttocks alone promote seat comfort among other body parts. In other words, the only body parts that affected seat comfort were the buttocks. Reducing buttock pressures requires a greater surface contact area around the buttocks on the seat pan.

These findings led us to propose a *physiological model of seating*. That is, seat comfort is associated with the transmission of sensory nerve signals of muscles to the cerebral nerve center in response to buttocks and thighs pressures while sitting. Seating comfort is greatest when pressures on buttock muscles approximate 30–50 mmHg. Exceeding that level of seat pressure leads to discomfort and may induce tissue necrosis if pressures exceed 70 mmHg for over 2 hours (LANDIS 1930, MINO 1997).

The extent that their finding applies to Fig. 44.3 may be debated. However, the reduction of sitting pressure undeniably promotes sitting comfort. Specific methods for this will be described in the next chapter.

Gluteus muscles tissue is strong enough to bear loads of around 60 kg. Increased pressures on thigh muscles, however, increase discomfort as those muscles are unable to bear loads equivalent to those in the buttocks.

3 A Trial Product and its Evaluation – An Experimental Manufacture of a Seat that Realizes Seating Comfort Derived from Zen Sitting

3.1 A Trial Product – A Concave Chair with a Seatpan Emulating the 3-D Curved Shape of the Buttocks

The design requirements from seating comfort defined by Zazen sitting and the related chair design theory described in the previous section are defined by three criteria: efficient body pressure distributions, reduced peak values of body pressures and postural stability.

(1) Improve seat pressure distributions

Securing the largest possible contact area of the sitting surface will broaden the area of body pressure distribution and minimize associated pressures/load per unit area.

(2) Reduce peak values of body pressures

The pressure distribution described earlier reduces mean values of seat pressures. The following pages describe the implications of reducing pressures on several body parts, including the buttocks. Adjustment of sitting-pressure peak values is performed largely on three body parts; i.e., gluteus maximus muscles, ischial tuberosities, and femoral region.

(3) Stabilize posture

Postural stability is among important elements not only for Zazen but also for almost all Eastern ways of seating. In the Zazen position, the projected area of a triangle formed by both knees and a zafu is larger than the area formed by chair sitting, while also configuring the three-point-support on both knees and zafu.

This configuration enhances postural stability (see Fig. 44.1) in ways that differ from chairs. Posture may be stabilized by expanding seatpan contact area. It would be desirable for pelvic support (also known as sacral support, suggested by WU et al. (1998), promote comfort over a wide range of body parts including the apex of gluteus maximus muscles.

3.2 Experiments and Evaluation

Chairs mounted with the prototype seatpan that emulates a 3-D shape of the buttocks (the “3D seatpan”) are shown in Fig. 44.4.

This chair was compared with a chair commonly available in the market mounted with a flat seatpan (the “flat seatpan”). Figure 44.5 compares sitting pressures when sitting on a flat seatpan and a plywood 3D seatpan chair. In both distribution charts, the highest sitting pressures center around the ischial tuberosities. The 3D seatpan as a trial product is seen to have greater area of sitting pressure distribution, which means superior body pressure distribution as mentioned previously.

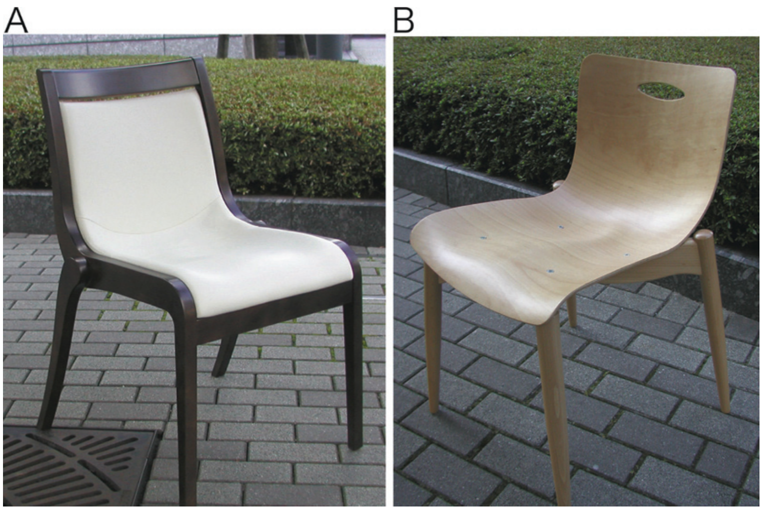

Fig. 44.4: **A**. 3D-seatpan chair upholstered with a thin cushion
B. A plywood 3D-seatpan chair

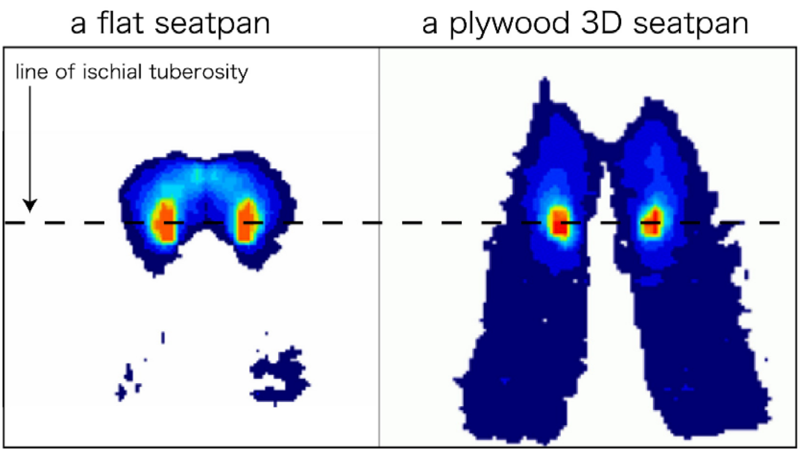

Fig. 44.5: Comparison of seat pressure distributions between a flat seatpan and a plywood 3D seatpan emulating a 3-D shape of the buttocks
Subject: A male in his 30s, 174 cm tall, weighing 64 kg
Flat seatpan: 105° backrest recline and 2.5° backward seatpan tilt
Upper limit of measuring range: 220 mmHg for both seatpans
Map: Black zone represent low pressures; white or gray zones higher pressures.
Measurement conducted at Gifu Pref. Human Life Technology Research Institute

Figure 44.5 demonstrates that the 3D seatpan has a greater area of contact surface (i.e., a greater number of active cells of the sensory device), while the average pressure for the 3D seatpan is 60% of that of the flat seat.

To investigate postural stability, the pelvis-position detecting device was used in the same manner as shown in Fig. 44.2, with pelvic tilt angles zeroed out at the standing position; positive and negative values signify forward and backward pelvic rotation, respectively. Findings from the 50-minute experiment are shown in Fig. 44.6.

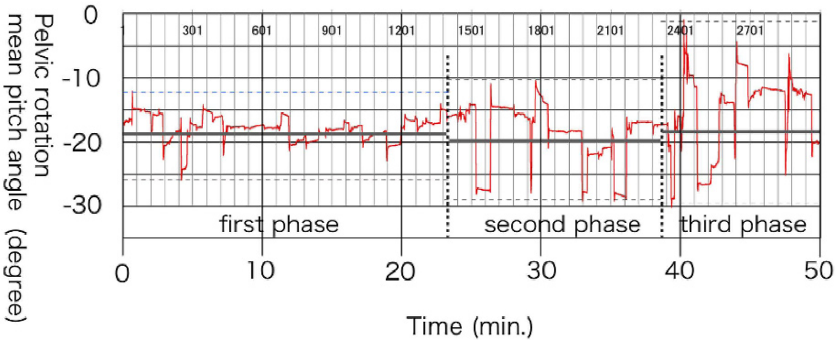

Fig. 44.6: Transition of pitch angles of pelvis tilt of a subject sitting on a 3D-seatpan chair upholstered with a thin cushion

Figure 44.6 demonstrates that:

(1) All mean pitch angles from three phases are seen to be better in comparison to those from chair sitting as shown in Fig. 44.2.

The first phase (0 sec to 25 min), in particular, presents a very stable posture with a mean pitch angle of –17.8°. The range of fluctuation also stands at minimum among three phases as shown in the figure.

(2) Growing fluctuations are seen in both second and third phases

This represents gradual instability of sitting postures with physiologically requested position shifts presumably included.

Duration: 50 minutes, **Subject:** a female weighing 63 kg, **Task:** reading

(3) Despite larger fluctuations, mean pitch angles remain between –18.7° and –15.2 ° all through three phases, indicating an excellent result.

(4) Zen monks, specialists in Zazen, are required to continue that posture for 90 minutes.

They grasp the special technique to adapt themselves for the practice after experiencing ascetic training. They expressed their full satisfaction with this seat. One of the reasons is linked with the fact mentioned in the item c, and the other reason will be described in the next section.

3.3 Linguistic Expression of Seating Comfort

Linguistic expression of seating comfort also is of significance. Whoever takes a seat on the 3D-seatpan chair expresses own feelings as if "wrapped," experiencing a sense of feeling being wrapped in a seat that fully disperses body pressures. An American expert used a word "cradle" (verb), which Merriam-Webster defines as "to support protectively or intimately." The phrase "feelings as if cradled" as an expression of seating comfort can be said to have implications that seating comfort is essentially linked to human ways of living (NORO 2008).

Compared with a "sense of fitness" appeared in a survey report (FUJINAMI & NORO 1990) as a superordinate concept, the "feelings as if cradled" would be considered to represent a sensuous experience of a higher order. The evaluation result mentioned above would imply that the trial seatpan could satisfy requirements from Buddhist monks nearly perfectly.

4 Conclusion

What is the difference between East and West in terms of chair design? The HFES 2006 panel session aimed to review and rethink the implications of regional and cultural differences on common assumptions and perspectives about seating comfort and seating design. This paper is based on the discussions from the past session, and focused on a trial manufacture of an Eastern chair.

Western chair features are designed to encourage sitters to move, thereby reportedly promoting more effective sitting work (e.g., armrests and seat swivel). In Eastern countries, it is more common to sit closer to the ground compared with Western chairs. There are a variety of seating postures in sitting close to the ground or floor. There also are quite a few cases where different sitting styles are considered dependant on gender. Among those sitting styles, Zen Buddhists attach more importance to spiritual effects brought by sitting, and consequently would never consider promoting sitting movements or work efficiency.

It would be incorrect, however, to make a snap conclusion that the difference of this kind stems simply from difference between chair sitting and floor sitting. There are two reasons for that. One is that seating tools used in the Eastern countries have a huge variety, with some resembling chair postures and seating design. The other is the fact that these days many Westerners sit on the floor in their way of life, while a growing number of Asian people also spend much time sitting on chairs. As such, the difference between East and West in terms of chairs lies in difference in their historical cultures.

The Eastern way of seating currently has a grave problem. That is to say, a growing number of young people have become familiar only with chair sitting since their childhood, while there are many elderly people who have come to feel pain in floor sitting with their legs crossed in a restricting manner.

In the second half of the 20th century, when higher efficiency was single-mindedly sought, Western-style chairs predominated. We cannot forget about having enjoyed comfortable and highly productive work by using efficient office chairs after 1980. Now, nearly ten years have passed into the 21st century. A great change is occurring in social, economic, and political environments. In the Western countries and Japan, it would be self-evident viewed from even a single problem with struggles over energy resources that we cannot promote social and economic developments with such paramount priority to efficiency as before.

Only a slightly smaller number of papers have been reported on ergonomic research on floor sitting than on chair sitting. The reason could be attributable to the longstanding trend of ergonomic research in Japan focusing their interest solely on technologies developed by Western countries. How should ergonomic research on chairs be like in the years to come? NORO et al. (2006) pointed out, by introducing specific examples, impasses seen in a Western-style approach in research and development of chairs. This research might be considered a breakthrough.

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45 Finger Fatigue: Blockings and Approximate Kinematic Invariances

Herbert Heuer

Among the classic problems of the physiology and psychology of work are the origins and consequences of fatigue (LUCZAK 1983; SCHMIDTKE 1965). Modern types of work with a high information-processing load and an intensive use of keyboards are often associated with different kinds of central and peripheral fatigue (ROHMERT & LUCZAK 1973). A signature of most varieties of fatigue is an increased variability of physiological and behavioral processes. As far as muscles are concerned, there is also a general reduction of force developed at a certain level of activation. In this chapter, I shall illustrate a rather unexpected, but observed consequence as well as an expected, but largely absent consequence of these basic phenomena. The unexpected, but observed consequences of variability are blockings. The expected, but largely absent consequences of muscle fatigue are kinematic changes.

Blockings can be observed in repetitive mental tasks as well as in repetitive movements. They are short interruptions of performance described first by BILLS (1931) and similar to lapses, which are the most prominent effects of sleep deprivation (HEUER et al. 2004). Blockings had been conceived as enforced rests by which a total breakdown of performance is prevented (BILLS 1935) or as attentional distractions (BROADBENT 1958). In rapid finger movements, blockings are experienced as loss of control (PETERS & DURDING 1979), according to my own experience as “the finger won’t do what it is commanded to do”. Conditions like time on task or sleep deprivation, which enhance variability, are associated with an increase in the frequency of blockings, whereas conditions like practice, which reduce variability, are associated with a reduced frequency of blockings (BILLS 1931; WARREN & CLARK 1937).

In the case of rapid finger movements, e.g., in typewriting, blockings are often incomplete rather than absent movements. In the case of typewriting, this results in omissions of letters (GRUDIN 1983). We studied blockings in a simplified task, rapid tapping in which the index finger oscillated up and down. Blockings were defined as movements that did not reach the contact key. If only inter-tap intervals were recorded, as is typically the case for rapid tapping, blockings would show up as inter-tap intervals of about twice the normal length.

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Why should blockings be related to variability? In general terms, the reason is that variability can perturb phase relations between signals involved in a task. Consider a single neuron that requires approximately synchronous inputs from two sources to reach firing threshold. Enhanced variability of neural activity can perturb the synchrony so that there is no more spatial summation, the threshold is missed and activity is cut off. Perhaps this simple illustrative example can be generalized to account for blockings in mental tasks. Rapid finger tapping has the advantage that certain signals that have to exhibit a particular phasing can be observed directly. These are the finger position and the myoelectric activity of flexors and extensors.

Figure 45.1 shows an example of a blocking in the last 10 s of a 30 s trial of rapid finger tapping (HEUER 1998). The blocking was associated with flexion that was too short (downward movement). The EMG, both of a flexor and an extensor muscle, revealed well-defined bursts, which have a certain phase relation to the finger position. As noted by WACHHOLDER and ALTENBURGER (1926), the phasing of the myoelectric activity depends on the frequency of the oscillatory movement. The higher the frequency, the earlier is extensor activity relative to extensions and flexor activity relative to flexions. In the example of Fig. 45.1, extensor activity occurs while the finger is on the contact key, thus preceding extension, and flexor activity occurs mainly during extension, thus preceding flexion.

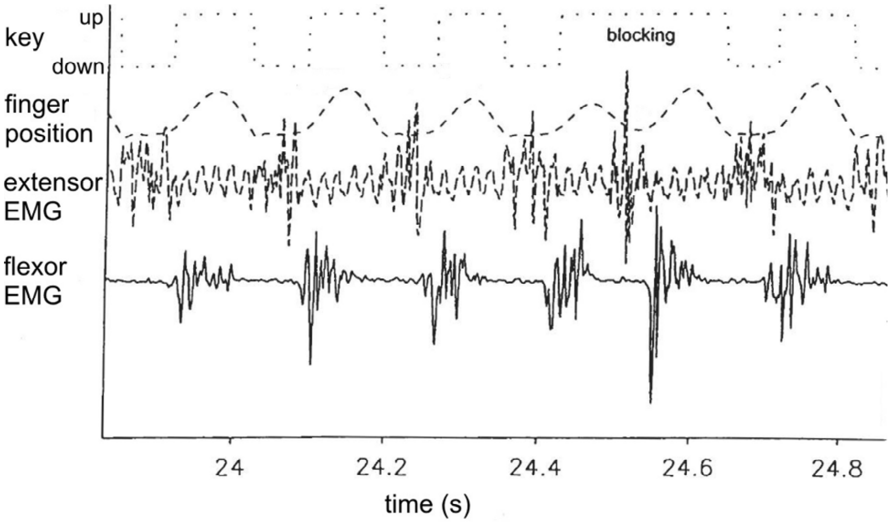

Fig. 45.1: Example of a single blocking in rapid finger tapping. Shown are the states of a contact key (up, down), the finger position and the myoelectric signals of an extensor and a flexor muscle (according to HEUER 1998)

The most consistent characteristic of blockings were early flexor bursts. In Fig. 45.2, the frequency distributions of two measures of relative timing are shown, both in a blocking and in the preceding three cycles of the oscillatory movement. R1 is the relative timing of the flexor bursts in the interval between lifting of the finger and movement reversal, that is, during extension. In blockings, flexor bursts tend to occur earlier in this interval. Thus, a greater part of the associated force is absorbed by reversing the upward movement, and the amplitude of the subsequent downward movement becomes smaller. R2 is the relative timing of the movement reversal in the interval between a flexor burst and the subsequent extensor burst. The movement reversal is relatively delayed in blockings – a consequence of the too early flexor bursts. For these analyses, the timing of each burst was determined as the center of mass of the rectified and smoothed EMG signal.

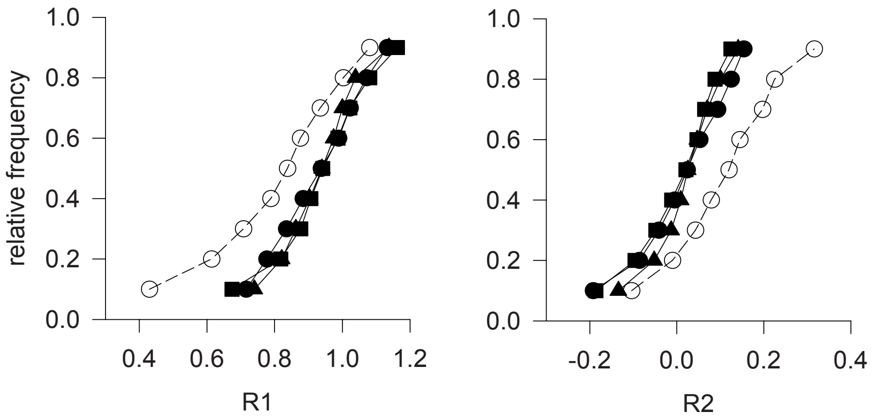

Fig. 45.2: Relative frequencies of two measures of relative timing in blockings (open symbols) and the preceding three movement cycles (filled symbols). R1 is the relative timing of the flexor burst in the interval between lifting of the finger and movement reversal; R2 is the relative timing of movement reversal (peak of finger position) in the interval between flexor burst and subsequent extensor burst

From Fig. 45.2 it is apparent that the relative timing patterns of blockings and normal cycles overlap. In fact, other conditions like reduced myoelectric activity can also contribute to blockings. These additional conditions, however, seem to be less consistent across individuals and time on task. From Fig. 45.2 it is also apparent that the deviant phasing of the flexor burst is a singular event in the blocking cycle; there is no gradual development of a deviant phasing in the preceding cycles. Later experiments showed that the phasing of bursts of muscle activity is indeed uncorrelated across successive cycles, that is, a deviation of the phasing from the mean, which – if too strong – can result in a blocking, is fully corrected in the next cycle (HEUER & SCHULNA 2002).

The findings show that blockings are largely a result of extreme phasings of muscle activity, which are random events. Therefore, it is obvious that blockings should become more frequent the larger the variability of the phasing is because larger variability is associated with a larger number of extreme phasings. In fact, in the first 10 s of a 30 s epoch of rapid finger tapping, blockings were less frequent than in the last 10 s (HEUER 1998). This was the case, although with time on task rapid tapping slowed down. If extreme phasings result from timing variability of bursts of myoelectric activity, their frequency should be reduced by slower rates of tapping. With a slower rate of tapping, a certain range of inter-burst intervals is mapped on a smaller range of phases than with faster tapping, so that consistent phasing can be maintained. Indeed, GLENCROSS (1973) found that the individual rate of cranking is correlated with the individual variability of inter-burst intervals. This is most likely because with a slower rate of cranking, a sufficiently consistent phasing of EMG bursts could even be achieved with more variable intervals.

Even though the role of temporal variability for blockings in repetitive finger movements is somewhat substantiated by the findings reported, the role of temporal variability for blockings in mental tasks remains rather speculative. On the one hand, from the general finding of increased performance variability with increasing time on task, one could infer that the variability of the underlying neural activity is increased as well. On the other hand, at least in the case of muscle fatigue, it has been observed that synchronization of motor-unit activity is enhanced rather than reduced (LIPPOLD et al. 1960; ARIHARA & SAKAMOTO 1999).

Muscle fatigue can be localized. It can be induced, e.g., by sustained submaximal contractions, and it can be different for the various muscles involved in the production of a particular movement pattern. From an applied perspective, a core characteristic of localized muscle fatigue is the modification of the transformation of muscle activity, as indicated by the myoelectric signal, into a force, as measured in an isometric-force task, or into a movement (CHAFFIN 1973). Thus, when some of the relevant muscles suffer from localized fatigue, kinematic characteristics of movements should be altered.

We examined kinematic alterations subsequent to localized muscle fatigue for rapid oscillations of the index finger in a horizontal plane (HEUER et al. 2002). First, there were three pretest trials, each 30 s in duration. Three immediate posttest trials followed, each one preceded by a 120 s period of sustained isometric finger flexion or extension at 50% maximal voluntary force. Finally, there were three delayed posttest trials that were not preceded by isometric contractions. Breaks between trials lasted one minute. The whole set of nine trials was repeated twice, once with isometric flexions and once with isometric extensions, to induce selective localized fatigue.

Figure 45.3 shows the time course of force, integrated myoelectric activity, and mean EMG frequency across six periods of about 20 s each. Both for extension and flexion, isometric force declined and the integrated EMG signal increased for flexor and extensor activity, respectively, whereas the mean frequency of the EMG of the respective muscles declined. The decline of mean frequency is a signature of muscle fatigue (e.g., MANNION & DOLAN 1996) when associated with enhanced rather than reduced myoelectric activity (LUTTMANN et al. 2000). These data clearly show the development of localized muscle fatigue in extensors and flexors, respectively. However, these changes were not fully selective. During sustained flexion there was also a decline of the mean frequency of the extensor with little change of myoelectric activity, and during sustained extension there was also an increase of the myoelectric activity of the flexor without a decline of mean frequency. The increased flexor activity is not necessarily a result of fatigue, but antagonistic flexor force might have been increased during sustained extension as well. Thus, most likely the effects of isometric extensions were more selective than the effects of isometric flexions.

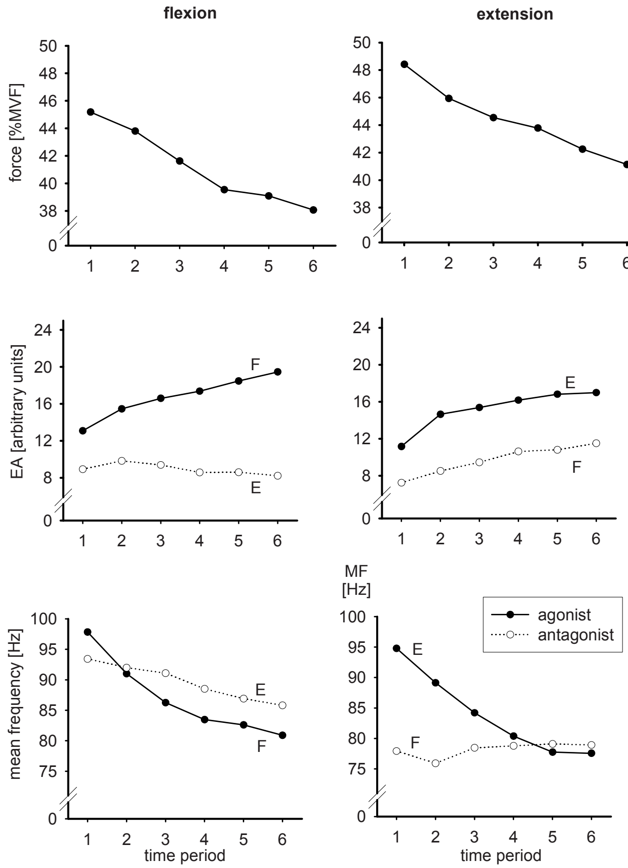

Fig. 45.3: Time course of force, integrated myoelectric activity (EA) and mean EMG frequency during 120 s of sustained flexion and extension (E: extensor, F: flexor)

Figure 45.4 shows an example recording from a pretest trial and an immediate posttest trial after sustained isometric extension. Among the conspicuous effects of the sustained extension were a reduced amplitude, a reduced frequency, an enhanced extensor activity and a reduced flexor activity. Across all trials and participants, the reduced amplitude was seen only in the first immediate posttest trial, but the frequency reduction was more consistent. In the pretest trials, the immediate posttest trials and the delayed posttest trials the cycle durations were 188, 198, and 187 ms, respectively. Note that these kinematic changes were independent of whether finger oscillations had been preceded by sustained flexions or sustained extensions. Regarding the myoelectric activity, there was an overall increase after sustained contractions, and after sustained flexions it was about the same for the antagonistic muscles. In contrast, after sustained extensions the increase of extensor activity was stronger than the increase of flexor activity. This again suggests that the effects of sustained extensions were more selective than the effects of sustained flexions.

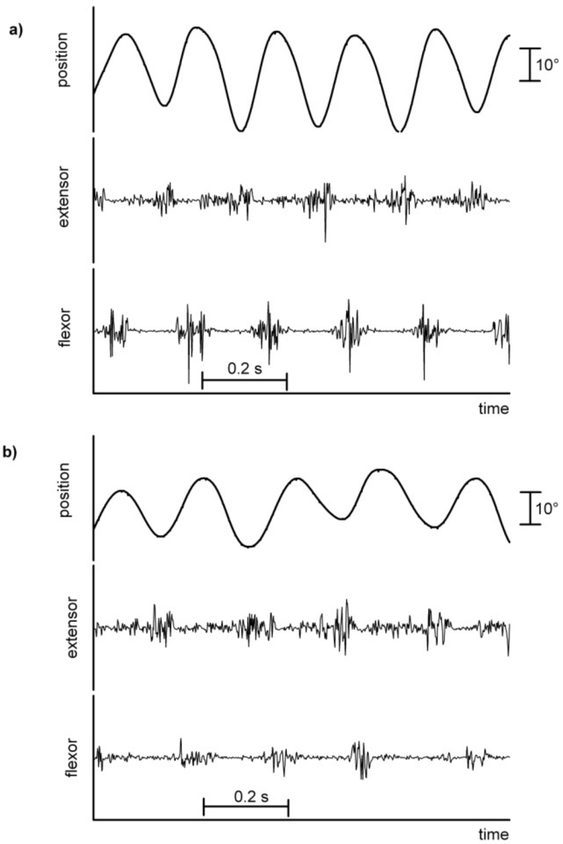

Fig. 45.4: Example recordings from a pretest trial (a) and an immediate posttest trial (b) after sustained isometric extension. Each graph shows an angular position of the index finger with myoelectric signals of an extensor and a flexor (according to HEUER et al. 2002)

The selective effects of sustained extensions on the functioning of the extensors should affect the shape of the oscillatory movements. In Fig. 45.5a the durations of flexions and extensions are shown; these are the intervals between successive movement reversals and were somewhat longer in the immediate posttest than in the pretest and the delayed posttest. However, the differences between the durations of extensions and flexions remained basically the same (1, –3, and –1 ms) in spite of the selective extensor fatigue. Figure 45.5b shows that the maintained difference between flexion and extension durations was accompanied by a changed pattern of EMG-burst timing. In the immediate posttest, extensor-burst-to-flexor-burst intervals were slightly reduced, and flexor-burst-to-extensor-burst intervals were noticeably increased. This change of timing resulted in a change of phasing, as shown in Fig. 45.5c. Relative to the start of flexions, the lead of flexor burst was increased, and relative to the start of extensions, the lag of extensor bursts was increased (these analyses were again based on the center of mass of the rectified and smoothed bursts.) Whatever the mechanisms are by which these subtle changes produce their effects, their result is a kinematic invariance, a constant relation between the durations of flexions and extensions of the repetitive movement pattern.

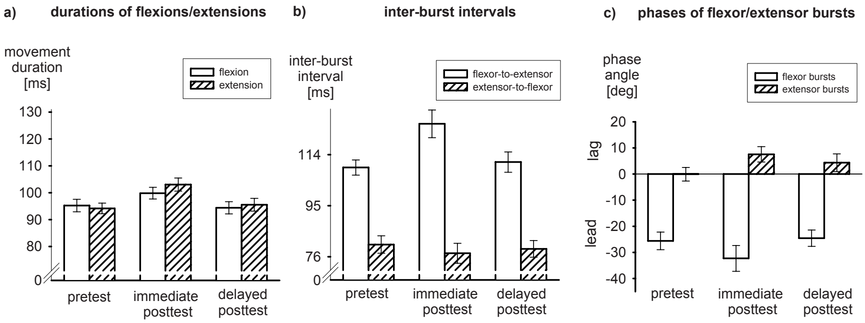

Fig. 45.5: Mean durations of flexions and extensions in pretest, immediate posttest, and delayed posttest (a) together with the associated inter-burst intervals (b). In (c) the mean phases of flexor and extensor bursts relative to the starts of flexions and extensions are shown (according to HEUER et al. 2002)

Approximate invariance of kinematic movement characteristics after induction of muscle fatigue has been reported for other movement tasks as well (e.g., JARIC 2000; CORCOS et al. 2002). For more complex tasks like throwing, a novel intersegmental organization has been observed after induction of localized muscle fatigue, which served to maintain performance, though with limited success (FORESTIER & NOUGIER 1998). To these findings, which are related to muscle fatigue, one can add findings related to the effects of different external forces acting on a moving limb or the effects of mechanical transformations as they occur when tools are used. When movements are performed upward (against gravity) and downward (with gravity), the kinematics are rather similar, but the patterns of myoelectric activity are grossly different (VIRJII-BABUL et al. 1994). When aiming movements are to be performed with a lever-like tool, the paths of the hand become curved even though they are approximately straight without a tool (MORASSO 1981); the result of the curvature of hand paths is approximate straightness of the paths of the tip of the lever-like tool (HEUER & SÜLZENBRÜCK 2009).

Findings like these point to a principle of distal action planning and control (PRINZ 1997), which is broadly consistent with the kind of goals humans pursue. These goals relate to the production of certain objects, to the assembly of certain parts, to reaching for various bits and pieces; they hardly ever relate to producing certain movements, and they basically never relate to the production of certain patterns of muscle activity. We can perceive objects, parts, bits, and pieces – we can even perceive our movements if we want to – but we cannot perceive muscle activity or muscle length (except in indirect ways). Our intentions are directed at goals and our perceptions allow the control of whether the goals are achieved. From this perspective, movements can be conceived as the production of intended perceptions (KALVERAM 1981). Beyond such intentions, post-intentional processes (HEUER 2004) serve to implement the appropriate motor patterns largely outside of conscious awareness. These processes are astonishingly robust, though not perfectly so. Potential effects of muscle fatigue and similar conditions can be largely ameliorated, e.g., by slowing down, by reorganizing patterns of muscle activity, etc. Post-intentional processes are principally enslaved by intentions, as they sometimes refuse to serve our intention even after long practice periods, and sometimes they do so with less than the desired perfection. This is when blockings will occur and muscle fatigue will result in kinematic changes.

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Part 7
Autonomous Organismic Systems

46 Neurobehavioral Tests as Evaluation of Neurotoxically Induced Impairments of Health

Andreas Seeber

1 Introduction

The multidisciplinary approach of ergonomics covers conceptions aiming at the prevention of harmful effects due to chemical exposure. There are general recommendations to avoid exposure related annoyances, impairments of well-being and deterioration of physiological and psychological functions (LUCZAK & VOLPERT 1997). Methodical details about such approaches are available in surveys on behavioral neurotoxicology (BERENT & ALBERS 2005, COSTA & MANZO 1998). Standardized test batteries were developed to measure in this context especially attention, perception, cognitive and psychomotor functions. These methods were also used in considering the effects of vibration, noise, cold and light (ECHEVERRIA et al. 1991). In this text a short overview on the characteristics and some epidemiological data of a frequently used test will be presented.

2 Some Premises

The basic assumption in this field is a causal relationship between measurable behavior and underlying morphological and physiological structures. Resulting from the impact of chemical exposure, changed morphological and physiological processes can cause changes in behavioral activities. However, there are large gaps between a biological path of action and the behavioral outcomes in relation to chemical exposures.

Measuring behavioral outcomes of exposure requires the evidence of a causal "bridge" from the biological to the behavioral level. A causal chain "external exposure → internal representation of the substance and/or of their metabolic substrate → action of the substance or of the metabolites in structures of the nervous

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system → measurable effects on behaviour and well-being" is assumed. Additionally, it is assumed that the level of exposure has a definable dose-response relation to the occurrence of behavioral effects. Under these presuppositions impairments of behavioral functions can serve as early indicators of neurotoxic effects. Following a proposal of a working group (SIMONSEN et al. 1994) different criteria of neurotoxicity of a chemical substance can be defined (Table 46.1). Self-reported and reversible symptoms are the weakest indicators whereas morphological (irreversible) changes in structures of the nervous system mark the strongest evidence of neurotoxicity.

Table 46.1: Hierarchical order for criteria of neurotoxicity; "(1)" low, "(6)" high evidence

Levels of evidence for neurotoxicity of a chemical
(1) Reversible, subjective symptoms
(2) Irreversible, subjective symptoms
(3) Biochemical changes
(4) Neurophysiologic and neurobehavioral changes
(5) Neurological changes
(6) Morphological changes

The evidence of neurobehavioral changes is only one step in the hierarchy. But this approach considers impacts of exposure that can be experienced individually. For example, patients with solvent induced toxic encephalopathy suffer from decelerated movements and cognitive processes but not from hidden changed neurophysiologic processes or morphological structures.

Behavioral functions and their changes in specific circumstances can be influenced by a broad range of confounding factors and/or conditions that may occur while performing the tests. Factors with long-term effects are for example age, level of education, verbal abilities as so-called pre-morbid intelligence. Typical actual conditions with impact on the measurements can be the time of day, the position of the test within the test sequence, and physical side conditions such as temperature or noise. Furthermore, life style factors like alcohol or drug consumption belong to the necessary factors to be considered. Interpreting any changes of behavioral functions as caused by chemical exposures at workplace requires firstly the proven evidence of exposure and secondly the clear exclusion of confounding factors and side conditions by appropriate statistical approaches. Figure 46.1 outlines the approach of a typical epidemiological study with neurobehavioral methods in this field (SEEBER et al. 2004, SCHÄPER et al. 2003, 2004).

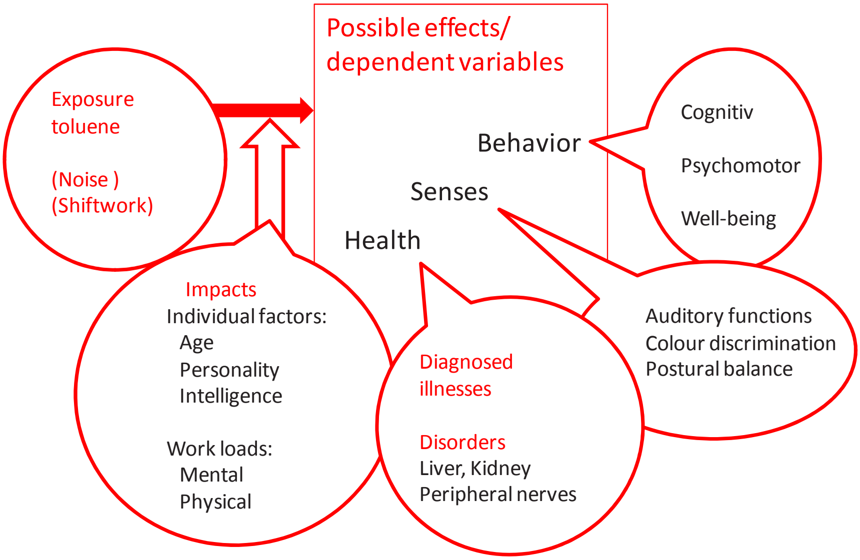

Fig. 46.1: Frame of an epidemiological study investigating toluene effects. The study approach included 4 repeated measurements of dependent variables over 5 years with extensive exposure measurements over the whole study period

In the following text only those changes of behaviour are outlined which can be measured by neuropsychological tests for cognitive and executive functions.

Cognitive functions are the base of information processing. Corresponding tests measure predominantly speed and accuracy of the function concerned. They refer to receptive functions (selection, acquisition, classification, and integration of information), memory and learning (information storage and retrieval), thinking (mental organization and reorganization of information), and mental activity variables (involved in cognitive operations as levels of consciousness, attention activities, and activity rate).

Executive functions refer to questions as to how or whether a person goes about doing something. If executive functions are impaired, the individual can no longer organize parallel tasks or maintain social relationships satisfactorily. Deficits in executive functions affect the capacity for self-control or self-direction (tendency to irritability, excitability, impulsivity, and rigidity) and the capacity to make shifts in attention or to initiate activity. Decreased motivation, planning and carrying out of sequences of activities also indicate impaired executive functions.

A clear distinction between cognitive and executive functions is difficult because both approaches interfere with each other. In the following section an example for the relatedness of testing cognitive and executive functions will be introduced. The test is based on the quick and precise substitution of digits for symbols or vice versa of symbols for digits according to a given rule.

3 The Symbol Digit Substitution Test

The Symbol Digit Substitution Test (SDST) is one of the oldest cognitive tests. According to the founder of the Wechsler Intelligence Scale it measures psychomotor speed and the score represents the ability to "concentrate".

There are two versions of the Symbol Digit task: In the traditional paper-pencil test the subjects have to draw a symbol in a blank space below a digit. The code for the symbols belonging to 9 digits is presented on the head line of the test sheet. After seven practice trials, the subject has to draw the symbols for randomly presented digits written in rows of 93 blank spaces. Test duration is limited to 90 seconds. This version is a part of the Wechsler Adult Intelligence Scale and standardized for age and education (TEWES 1991).

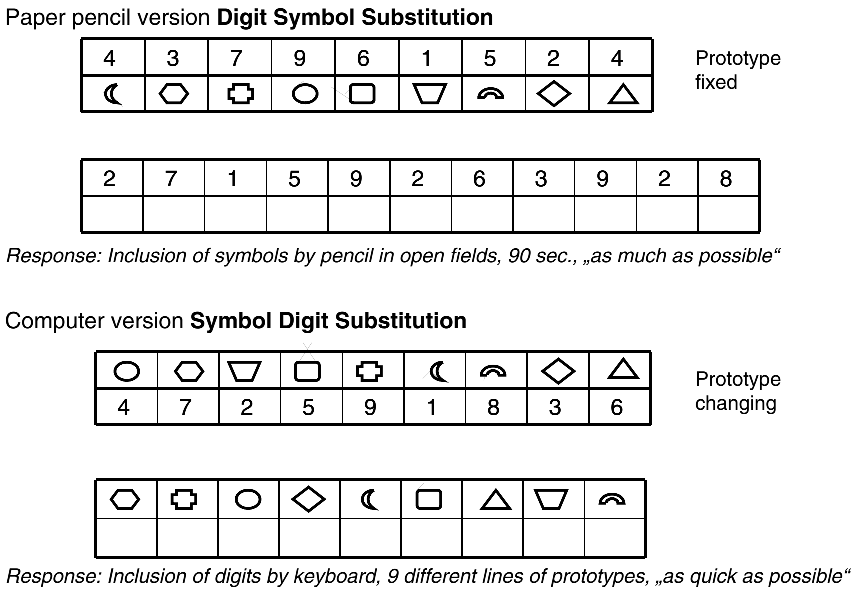

Fig. 46.2: The Symbol Digit Substitution Test paradigm. The signs do not correspond to the original versions

Another version is carried out as a computer administered test (Table 46.2). On the head line of the screen nine different pairs of symbols for digits are given. As the test performance, the subject has to press the keys of the digits for the corresponding symbols presented in a random order. Translations from symbols to digits are required. After each row of ten trials the code changes. This test is part of the Swedish Performance Evaluation System (IREGREN et al. 1996) and of the Neurobehavioral Evaluation System (LETZ 2000).

The correspondence of the psychological structure of both tasks (paper-pencil version "p-p v." versus PC version "PC v.") has been checked by factor analyses which include both the tests considered and other tests aimed at convergent or divergent psychological functions (HOOISMA 1990). Corresponding loadings of both tests were shown despite different outcomes: number of correct trials per time for p-p v. and the mean time per correct responses for PC v. With respect to the factor loadings the authors concluded "complex perceptual motor performance" as psychological function measured. A similar conclusion was drawn in a second study with different tests in the factor analyses (LETZ et al. 1996). "Speed of processing and fine motor abilities" was the label for the corresponding factor.

Table 46.2: Similarities and differences of the versions of the Symbol Digit Substitution Test (SDST)

Similarities and differences of the Digit Symbol Test (DST, paper-pencil version) and the Symbol Digit Substitution task (SDS, PC version)

- The number of about 100 trials to administer the substitution task agrees.
- The core performance to substitute for digits and symbols corresponds, the direction of substitution differs.
- DST: The time is restricted and the number of correct signs during 90 seconds is used as the test score. SDS: The time to handle with the appearing rows of symbols is used as test score.
- The psychomotor part is changed from drawing of symbols (DST) to quick and accurate movements on the keyboard (SDS).
- The cognitive coding part of the task can be supported by learning of the code in the version DST, but not in the version SDS.
- The reliability of the test versions was checked repeatedly and fulfills usual criteria (split half coefficient r = 0.95; retest reliabilities between r = 0.70 and r = 0.90).
- The psychological structure of the tests is comparable.

4 The Symbol Digit Substitution Test in Neurobehavioral Studies

Most test batteries in neurobehavioral studies use the paradigm of Symbol Digit Substitution. An analysis of 185 epidemiological cross-sectional studies published before 1989 demonstrated the "top position" of the SDST as one of the most accepted neurobehavioral tests. In 27 studies the paper pencil version, and in 4 studies the PC-version were used. A later analysis of 25 studies published between 1989 and 1994 showed the use of the paper-pencil version in 12 studies, and of the PC version in 8 studies. Now the question arises as to which portions of variance of the SDMT variables are associated to chemical exposure.

5 The Symbol Digit Substitution Test and Solvent Exposure: An Example from Cross-Sectional Studies

Five statistically well controlled studies on neurobehavioral effects due to exposures to solvent mixtures in paint manufacturing can be compared (SEEBER et al. 1996). The individual cumulative exposure (CE, ppm -pars per million- years as measurement of dose) as well as the individual Lifetime Weighted Average Exposure (LWAE, ppm as averaged concentration in the air of the workplace) of total hydrocarbons has been used as exposure characteristics. Twenty one solvents were listed as compounds of the mixtures. Partly, the Hygienic Effect (HE, sum of portions of concentration to the TLV – threshold limit value – for the compounds) for the mixture was calculated as information on exposure. The comparison of the LWAE for total hydrocarbons in different jobs showed roughly comparable exposure conditions in USA, Germany and Taiwan. On the other hand, the Swedish and the British studies are based on comparable HE years in the groups. Under these exposure conditions, the association of the SDMT to exposure indices has been investigated. The US study showed in a subgroup of 144 exposed workers (>10 years of exposure), through a linear regression model, significant dose response relations to LWAE. The German study showed with 40 exposed workers (about 13 years of exposure) by partial correlations and linear regressions significant dose response relations to LWAE and CE. Up to 35% of the variance could be explained by the reaction time of SDMT. The British study with 104 exposed workers, the Taiwanese study with 164 exposed workers, and the Swedish study with 49 exposed workers could not replicate the results of the first mentioned investigations with respect to SDST.

Additionally, in this article test results in painters and floorlayers were analyzed by evaluating four studies. Litres of solvent used per day were outlined as measure of exposure. The “litres per day x years” (dose L/d years) varied between about 26 and 71. A Danish study with 85 painters, an US study with 90 painters, a case study with 14 painters and floorlayers as well as a Swedish study with 25 floorlayers showed repeated dose response relations using partial correlations, linear regressions or non parametric statistics.

Obviously, the SDMT co-varies with the indices or classifications of solvent exposure. No other performance test in these analyses had such “discriminatory power” between non-exposed, low exposed and high exposed workers.

6 The Symbol Digit Substitution Test in Meta-Analyses

After exemplary descriptions of associations between test results and chemical exposures a survey on epidemiological data should be given. Representative meta-analyses were published about occupational exposure to lead, mercury, toluene, aluminum, and solvent mixtures.

At first, the occupational background of the workers included might have been an issue of interest. Occupational sources of inorganic lead exposure (meta-analyses excluded organic compounds) are smelting, welding, and cutting of lead containing materials, spray painting or scraping of lead paints, but also activities as lead miners, type formers, cable makers, and lead glass workers. Mercury exposure (meta-analyses excluded organic compounds) is possible in dentistry, in the recycling of electronic devices, dealing with thermometers (in their historical form), thermostats, barometers, electrical switches and light bulbs and in some chemical and pharmaceutical manufacturing. The toluene exposure refers in the analyses presented predominantly to workplaces in rotogravure printing. Aluminum exposure occurs more recently in automotive and aerospace industries with increasing tendencies whereas the before mentioned lead and mercury exposures rather reflect workplaces in the past with decreasing occurrence. Exposure to solvent mixtures is a typical risk at workplaces of house-, care- and ship-painting, in paint manufacturing, in cleaning processes of metals and partly in the printing and petrochemical industry.

These meta-analyses focus on the question of whether or not a particular test reflects similar effects in different studies of a particular chemical exposure. At least three results of different studies have to have published according to a list of criteria before a meta-analytical result can be completed. Evidence for significant associations between test results and exposures is given if the calculated overall effect size (d_{RE}; standardized difference between the mean values of exposed and controls) of the test results included can be declared as significant. In Table 46.3 this is shown by a 95% confidence interval within the "–" range. For example, in the meta-analyses of GOODMAN et al. (2002) on effects of occupational lead exposures "d_{RE} = – 0.32" and "CI = – 0.59/– 0.05" indicate that 12 studies can be summarized with a general conclusion: There is a significant tendency that lead-exposed workers perform the test SDS (p-p v.) significantly worse compared to the controls in the studies. This is true at an exposure level classified by a range 240 – 630 µg Pb/l blood. If the confidence interval exceeds the zero-point d_{RE} can be interpreted only with caution. However, the sign "–" indicates that a pattern exists of worse performance among the exposed workers compared to the controls at a given exposure level.

Table 46.3 demonstrates the widespread use of the Symbol-Digit-Substitution task in neurobehavioral studies. It also shows the concordant evidence of exposure related test results in different studies with respect to lead, aluminum and solvent mixtures. The analyses of mercury and toluene effects doe not exhibit concordant results on exposure related changes of the test performance. Finally the table also indicates exposure levels with the elevated risk to suffer from a delayed cognitive coding process, which is examined by this test. However, whether or not any attention-related impairment of a worker should be estimated as an adverse effect has to be evaluated according to additional criteria (e.g. DGUV 2007).

Table 46.3: Results of meta-analyses (me-a). Overall effect sizes (d_{RE}) are selected according to the random model of meta-analyses. The basis of calculation is comparable between the studies but not identic. "Studies": Number of studies included/… available in literature; "Tests": Number of tests analysed in me-a/… used in the studies included; "Subjects": Number of exposed workers/… of controls examined with tests of me-a. "n. a." if data are not available in the article cited. "p-p v." pencil-paper version, "PC v." PC version of the test

Chemical (Reference)	Study characteristics	Studies with SDS task results in me-a	Overall effect size (d_{RE}) of SDS task results	95% confidence interval of d_{RE}	Overall exposure representing the SDS task result
Lead (Meyer-Baron, Seeber 2000)	Studies 12 / 22 Tests 13 / 48 Subjects 914 / 743	8	- 0.28	- 1.32 / 0.76	421 µg lead / L blood
Lead (Goodman et al. 2002)	Studies 22 / 140 Tests 21 / n.a. Subjects 3533 / 1511	12	- 0.32	- 0.59 / - 0.05	240 – 630 µg Pb / L blood
Mercury (Meyer-Baron et al. 2002)	Studies 12 / 44 Tests 14 / 17 Subjects 686 / 579	3	- 0.35	- 0.74 / 1.44	22 µg Hg / g create-nine in urine
Toluene (Meyer-Baron 2005)	Studies 10 / 22 Tests 4 / 33 Subjects 447 / 408	4 p-p v. 3 PC v.	- 0.23 + 0.29	Non-significance indicated	Room air: 89 ppm 33 ppm
Aluminum (Meyer-Baron et al. 2007)	Studies 15 / 21 Tests 6 / n.a. Subjects 449 / 315	4 p-p v. 3 PC v.	- 0.43 - 0.46	- 0.77 / - 0.08 - 0.60 / 1.53	30 – 61 µg Al / L urine 22 – 133 µg Al / L urine
Solvents (Meyer-Baron et al. 2008)	Studies 46 / 135 Tests 48 / n.a. Subjects 3390 / 2827	19	- 0.35	- 0.49 / - 0.22	Explained variance (R^2) of d_{RE} by exposure index: 14%

7 Conclusion

Prevention of harmful effects of chemicals bases on published risk assessments which process the available scientific data on harmful effects of the substance focused. Recommendations for limit setting (e.g. MAK and BAT values, Maximum Concentrations and Biological Tolerance Values at the workplace) are based on such risk assessments. Neurobehavioral effects are one of the domains outlined routinely if adequate literature is available. The store of empirical data has been extended in the last twenty years with respect to a broad spectrum of substances. The Symbol Digit Substitution paradigm belongs to those neuropsychological tests which are very often used in such studies. It can provide substantial information on slight cognitive changes due to chemical exposures at workplaces. Ergonomists can rely on such data as early indicators for impairments of health and well-being if similar effects were outlined repeatedly in different studies. Any single piece of information on an exposure-related effect should be evaluated only with caution.

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