From Control to Cognition: Historical Views on Human Engineering[1]

Gunnar Johannsen

Systems Engineering and Human-Machine Systems

University of Kassel, Germany

E-mail : g.johannsen(at)uni-kassel.de

www.imat.maschinenbau.uni-kassel.de,   www.gunnar-johannsen. de

Abstract: The historical development of the field of Human Engineering is presented here, starting from its first roots in the 1930s and early 1940s up to the recent perspective of a coherent Human-Machine Systems Science. The early roots of the discipline are based on experimental psychology, ergonomics, and control, decision, and communication theories. The investigations of electromechanical displays and control devices have been followed by the first perception-action models of manual control and the optimal control model in the 1960s and early 1970s. A particular application domain with also current new importance is the modelling of driving tasks, now under the view of driver assistance systems. Here and much more in the domains of industrial and service applications, an evolution has occurred over the past decades towards investigating more sophisticated tasks which need more cognitive involvement of the human. Supervisory control, human-computer interaction, decision making, and problem solving activities are outlined in this paper. Applications cover a broad spectrum from engineering and beyond. Also, a comparison with music performance is given. In general, multimodal interaction and gestural control have contributed to a more transdisciplinary view on human control, cognition, and emotion. Both, human-machine interfaces as well as knowledge-based assistance and support systems are nowadays developed under such perspective.

Keywords: human engineering, human-machine systems, models of manual control, supervisory control, human-computer interaction, cognitive systems engineering, driver assistance systems, visualization, auditory displays.

Gunnar Johannsen was Professor of Systems Engineering and Human-Machine Systems from 1982 to 2006 in the University of Kassel, Germany and has been an orchestral conductor since 1999. He received his Dipl.-Ing. degree (1967) in communication and information engineering and the Dr.-Ing. degree (1971) in flight guidance and manual control from the Technical University of Berlin, Germany. In addition, he studied music for three years within the sound engineering curriculum at the University School of Music, Berlin. In 1980, he habilitated (Dr. habil.) at the Technical University of Aachen, Germany. From 1971 to 1982, he was division head in the Research Institute for Human Engineering near Bonn, Germany. His overseas work experience includes longer research commitments in the USA (1977–1978), Japan (1995 and 2004), Austria (1999), and Canada (2004). He founded and chaired the Technical Committee on Human-Machine Systems (1981–1990) in IFAC (International Federation of Automatic Control. He is Life Fellow of the IEEE (Institute of Electrical and Electronics Engineers) "for contributions to human-machine systems engineering, cognitive ergonomics, human-computer interface design, and human-centered automation". Further, he was recipient of a Japanese-German Research Award (granted by the Japan Society for the Promotion of Science). In 2005, he received the title of Docteur Honoris Causa (Dr. h.c.) from the Université de Valenciennes et du Hainaut-Cambrésis in North France.

1. Introduction

The field of Human Engineering developed to a transdisciplinary area of science and technology of its own, over the last century. It deals with human-machine systems, human-computer interaction, and human-robot communication together with all human factors issues of work, leisure, and entertainment environments which include any kind of interactive or cooperative technical system. Several historical eras, from the very beginning of the field until 2000, are outlined and explained in this paper. Then, a spectrum from car driving to music is presented in order to exemplify some of the new developments since 2000. Possible future perspectives are indicated in the last chapter.

2. Historical Eras until 2000

2.1 Historical Era 1: until 1940

Human Engineering can briefly be defined as human control over technology and design or adaptation of technology for human use. This very general definition contains aspects which obviously exist since the existence of humankind. Even almost 2000 years ago, the code of Hammurabi in the old Babylon

---

[1] An earlier version of this paper was presented at the 24th European Annual Conference on Human Decision Making and Manual Control (EAM 2005) during October 17–19, 2005 at the Institute of Communication and Computer Systems in Athens, Greece and appeared in its CD-ROM Proceedings in a small edition (Johannsen, 2005). An overview of the paper with selected viewgraphs was published in the Proceedings of the DAAD-German Summer Academy at the University Duisburg-Essen (Johannsen, 2006a). — The first version of this contribution was an invited lecture presented at the 10th Anniversary of LAMIH (Laboratoire d'Automatique, de Mécanique, et d'Informatique industrielles et Humaines) at UVHC, on the day before receiving the title of Docteur Honoris Causa (Dr. h.c.) from the Université de Valenciennes et du Hainaut-Cambrésis (UVHC) in France on March 24, 2005.

indicates that designers are responsible for poor design decisions. One of these rules in this code says: if a builder of a house builds a house which falls in and kills a person living in this house, this builder should be severely punished. Of course, this is old Babylon but the general idea that designers should be responsible for systems, which are built for human use, still holds and it is, in some way, an early rule of usability. Later on, early Engineering Designs certainly influenced the field of Human Engineering a lot. Some of these designs were at least implicitly dealing with usability and with human engineering: for example, those by Leonardo da Vinci, Bell, Edison, Daimler, Benz, the Lilienthals and the Wrights.

The other more extensive sources of science in this field came from Scientific Management and, particularly, from Experimental Psychology. The famous Frederick Taylor (1911), responsible for the Taylorism, performed work, time and motion studies. What he also did, he invented the separation of planning and executing tasks which holds for many workplaces in industry until today whether it is always good or not.

Experimental Psychology and also Psychophysics date back into the 19th century with Weber and Fechner, Helmholtz, Ebbinghaus and Wundt. The early Cognitive Psychology, particularly the Gestalt-Psychology work started already in the 1920s in Berlin with Köhler, Koffka, Lewin, and Wertheimer who then later went to the United States. This work was not taken into account for some time. Only in the 1980s, Cognitive Psychology became important again.

2.2 Historical Era 2: 1940 – 1955

For the field of Human Engineering in total – Human Factors Engineering and Human-Machine Systems, the first years of the second period (1940 – 1955) were very important. As Sheridan stated in his keynote speech at the IFAC[2] Man-Machine Systems Conference in 1985: "The first few years of this period saw most developed nations of the world locked in an intense struggle of men and machines" (Sheridan, 1986). Application domains were radar, sonar, gun aiming, aircraft guidance, aircraft control, etc. At that time in this period of 1940 –1955, the term Man-Machine Systems was almost synonymous with Human Factors Engineering. The field was more empirical, and almost no theory was developed. Sometimes, it was just simply called "knobs and dials". Although the cognitive psychology domain existed already for some while, it was more the behavioural experimentation which was the main focus of investigation (Sanders and McCormick, 1993).

2.3 Historical Era 3: 1955 – 1970

The next era of 15 years from 1955 – 1970 became more theoretical in addition to empirical. There were a lot of new theories developed, also particularly through the World War II period. These are control theory as well as signal detection, decision, and communication theories which, altogether later, form the bases for what we call today systems engineering and systems theory. Through these theories, Man-Machine Systems became a discipline with a quantitative systems-theoretical basis (Sheridan and Ferrell, 1974; see also Johannsen, 1993) and, thus, became a bit separate development from Human Factors Engineering which continued more in a way of pure empirical studies, sometimes almost up to today. Also in this historical era between 1955 and 1970, the first journals were published in this field, particularly the IEEE Transactions on Human Factors in Electronics, as they were called first since 1960, then a few years later named into Transactions on Man-Machine Systems and, since 1971, into Systems, Man, and Cybernetics. The main domains of interest were manual tracking, as in the era before, and, then in addition, also human operator models for tracking tasks and beyond. The influence of bandwidth and controlled processes was investigated: Quasi-linear, crossover, and optimal control models were developed as well as, later then also adaptive, sampled-data, and non-linear models.

---

[2] International Federation of Automatic Control — www.ifac-control.org

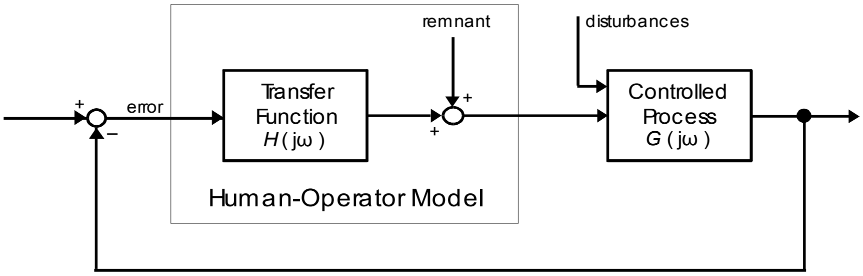


Figure 1. Control Loop with Quasi-Linear Model of the Human Operator.

The classical Quasi-Linear Operator Models are shown with the control loop of Fig. 1 (McRuer and Jex, 1967; McRuer and Weir, 1969; McRuer, 1980). The Crossover Model is a particular important suggestion, empirically proved by McRuer and his co-workers. The main idea is that the quasi-linear transfer function of the human operator together with the controlled process, thus, the open loop transfer function G_o of the control loop, can be characterized by the following relatively simple equation, in the neighbourhood of the crossover frequency:

$$G_o\,(j\omega) = H\,(j\omega) \cdot G\,(j\omega) = \frac{\omega_c}{j\omega}\, e^{-j\omega\tau_e}$$

for ω near ω_c (crossover frequency)

with 2 parameters (ω_c and $\tau_e = \tau + T_N$).

This model has only two parameters, namely the crossover frequency ω_c and the effective time delay τ_e which is the time delay τ of the human operator and the neuromuscular lag time T_N.

Another very famous model is the Optimal Control Model of the human operator developed by Kleinman, Baron, and Levison (1970) which is more mathematical than the quasi-linear models but also very well-suited for multi-variable applications. As shown in Fig. 2, it is subdivided in the perception and attentional allocation part, the central information processing part, and the action part where optimal control and optimal estimation with Kalman filter and predictor are separable, and where neuromuscular dynamics are included in the criterion function. The perceptual thresholds and the time delay are taken over from the quasi-linear model. The optimal control model was used in many application domains, particularly in aircraft guidance but also in other vehicular guidance and several further applications. It was also extended to situations where the control process was automatized and the human operator was modelled as an optimal decision maker for monitoring tasks. Then, the Action part of the kind shown in Fig. 2 is changed into a decision module.

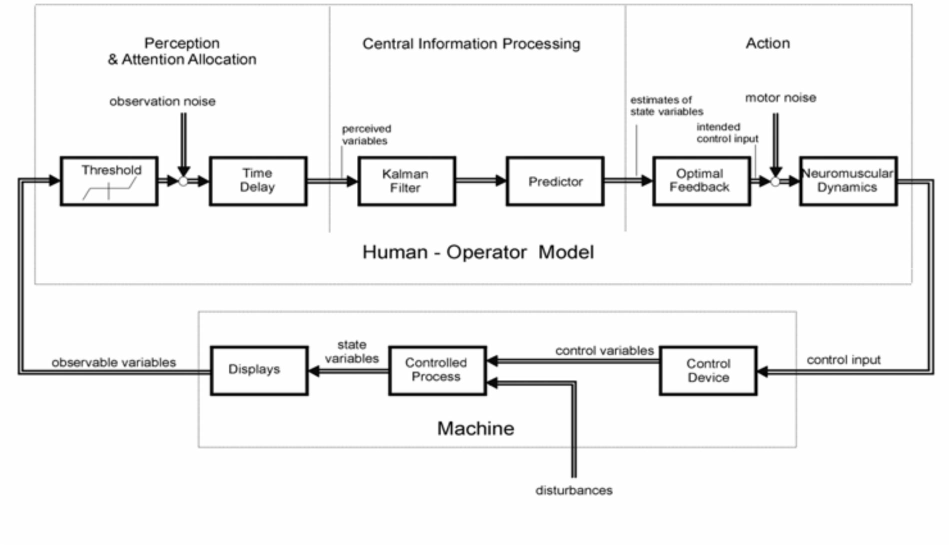


Figure 2. Optimal Control Model of the Human Operator.

2.4 Historical Era 4: 1970 – 1985

The era of 1970 – 1985 is the era of the most rapid development of computer technology which has ever occurred so far. The impact of computers was very dramatic; particularly such areas like automation, computer graphics, and also knowledge-based systems can be mentioned here. The complexity of the systems to be controlled by humans, or supervised and controlled by humans, has even become higher, structurally as well as functionally, through the addition of computerized systems. Thus, there was not a replacement of humans by automation as often feared and also discussed in the areas of social effects of automation. However, human roles and jobs changed towards supervisory control. Also, studies on mental workload in situations of computerized systems have been investigated more carefully.

Another conceptual development in this era is the notion of Supervisory Control where Sheridan introduced the idea of human-interactive versus task-interactive computers; see Fig. 3 (Ferrell and Sheridan, 1967; Sheridan, 1986, 1992, 2002; Sheridan and Johannsen, 1976). Several functions belong to this notion of Supervisory Control, particularly planning, teaching, monitoring, diagnosing, intervening, and learning. In addition to the tasks of controlling systems, problem solving tasks have been investigated more carefully, particularly fault management in general and, more especially, diagnosis tasks and decision making behaviour in all kinds of applications.

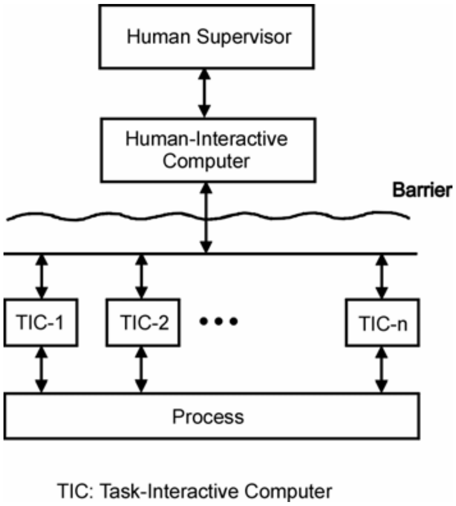


Figure 3. Supervisory Control with Human-Interactive and Task-Interactive Computers.

The field of Human-Computer Interaction, which sometimes today seems to be a completely independent field, is much younger than the field of Human-Machine Interaction or Human-Machine Systems. It developed more strongly only in the early 1980s and belonged also to the Human-Machine Systems field from the very beginning. However, it also focussed more on stand-alone applications of Human-Computer Interaction like in the service sectors, the financial areas etc. Some of the early problems, which have been investigated, are dialogues between human and software systems, multitasking, support of Human-Computer Interaction tasks, etc. The first international conferences showed up in 1982. The first Man-Machine Systems Conference of IFAC included an extensive session on human-computer interaction (Johannsen and Rijnsdorp, 1983). In addition, a larger conference, the first internationally well-recognized one in the world, on Human-Computer Interaction, was also arranged in 1982, by the SIGCHI[3] of ACM[4], where at once several hundreds of people attended (Nichols and Schneider, 1982). Both conference series have regularly been organized up to now. Their latest conferences have been held in Seoul as the 10th event in case of the IFAC Human-Machine Systems Symposium[5] (Yoon, 2007) and in San Jose as the 25th event in case of the Conference on Human Factors in Computing Systems[6] (Rosson, Gilmore, et al. 2007). Another important conference series on human-computer interaction is also regularly held. It is the International Conference on Human-Computer Interaction – the HCI International[7] – with its 12th event in July 2007 in Beijing[8].

---

[3] ACM's Special Interest Group on Computer-Human Interaction — www.sigchi.org

[4] Association for Computing Machinery — www.acm.org

[5] www.ifac-hms-2007.com

[6] www.chi2007.org

[7] www.hci-international.org

[8] www.hcii2007.org

Coming back to the notion of Supervisory Control, as seen in Fig. 3, there are layers of computers, at least two layers. Sometimes, there are several layers in between. The Human-Interactive Computer is a kind of coordinating computer and the one which allows the human to supervise the computerized system altogether. On the other hand, the Task-Interactive Computers are process-near, and they are often decentralized, even in a distributed manner controlling sub-processes and coordinating, sometimes to a certain extent, among each others. Particularly, they are coordinated through the next layer in the hierarchy. Early applications dealt also with tele-remote applications. Thus in some way, there is a barrier between the Human-Interactive Computer and the Task-Interactive Computers and the Process. Examples exist in space or undersea applications or in remote areas with safety critical or dangerous, hazardous environments where we don't want to have the human being present. So, we have tele-presence systems, remote systems. In addition, the barrier can also be seen as a psychological barrier because the human does not directly control any longer the process as before.

It is enlightening to contrast Human-Computer and Human-Machine Interaction a bit with the structure of Human-Machine Systems as shown in Fig. 4 (Johannsen, 1995, 2004). On one side, there are the human users, on the other side there is the machine which is either the dynamic technical system with the dynamic technical process or it can also be a software application which may be a stand-alone application as in Human-Computer Interaction. Thus, the specifity of the Human-Machine Interaction (in the narrower sense) is that a dynamic technical process is running in real-time. Supervision and Control Systems and also Knowledge-Based Decision Support Systems with Libraries are extensions of the technical system and can also be sub-modules of the software application. Several human user classes can be distinguished, such as Operators, Engineers, Maintenance Personnel, and Managers depending on the specific application domain. In the Human-Machine Interface, it is common to differentiate between presentation and dialogue, and the more technical application interface. More advanced functionalities of the Human-Machine Interface may include User Models and Application Models as well as Explanation and Tutoring Facilities.

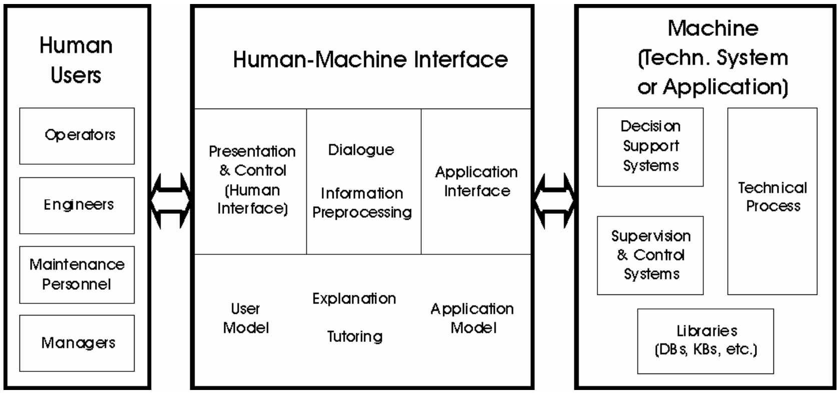


Figure 4. Structure of Human-Machine Systems (after Johannsen, 1995).

The further development of the field of Human-Machine Systems and Human Engineering, in the era between 1985 and 2000, includes Human-Machine Interfaces, Human-Robot Communication, which both started also in the era before, Decision Support, Computational Intelligence, and Cognitive Engineering as well as, later, Multimodal Interaction and Cooperation. A closer look on all these four follows.

The development of Human-Machine Interfaces started already before and continued with using new technologies for visualization, particularly computer graphics technologies, the development of more flexible visualizations, window screens, touch screens, and better interaction technologies (see, e.g., Johannsen, 1993). The possibilities of representing information about the application and the user have been included. This has particularly been done also by user, application, and task modelling. The dialogue, thus, the information handling, the organization of the information between human and machine, is further developed as well, and more explicitly separated from the visualization. Later, functional interfaces have been developed, particularly some such as the Multi-Flow-Modelling technique by Morten Lind (1990) or the Ecological Interface Design by Kim Vicente (Vicente and Rasmussen, 1990).

The second field of Human-Robot Communication developed in some way astonishingly, because it developed to a certain degree independently, but also under the roof of Human-Machine Systems Conferences where it belongs. Tele-operation was mentioned already in the context of Human Supervisory Control. Human-telemanipulator interaction became important for remote applications such as flight, space or undersea where predictive displays were used to compensate for the time delays, particularly in the space domains. Haptic feedback was developed as a very important information source. In medical applications, enough sensitive feedback is needed when the manipulator touches tissues of the human body. It is very important to have touch. Thus, haptic feedback and haptic systems are of very much importance in research up to today. Other developments in computer science, which are important for Human-Robot Communication and have been developed there with some emphasis, are Multi-Agent Systems and Communication and Collaboration. Multi-Agent Systems have to deal with well designed function and task allocations. This is a field in which the group in Valenciennes, the LAIH[9] in the beginning and since 1994 the LAMIH[10], have early on contributed a lot, particularly, also with the dissertation of Patrick Millot (1988). Other important issues of the Multi-Agent Systems are (semi-) autonomous units and the interaction between these with higher levels in the system and also with the human operator or supervisor. In the sub-area of Communication and Collaboration, more technical issues such as communication protocols have been investigated, as well as the problems of situation and mode awareness and the way of cooperative work, the way of several humans working together with several or one machine-system.

The third field in this era from 1985 to 2000 is "Decision Support, Computational Intelligence, and Cognitive Engineering". Decision Support mainly meant, in that era, heuristic expert systems, i.e. symbolic knowledge computation, but also Bayesian normative decision strategies, for example. The Computational Intelligence Techniques further developed beyond these technologies for the decision aids and were used not only for decision support but also for control and even for display development, etc. Fuzzy logic, neural networks, and evolutionary algorithms have been applied, to name the most important Computational Intelligence Techniques.

As stated before, the Cognitive Psychology era started already very early but, then later, it was not so much used in the field of Human-Machine Systems for a long time. The behavioural views were more prominent for some time, even several mechanistic ideas through the influence of the engineering theories. Then later, the model of computer architecture and behaviour was used and, through that, the cognitive approach, and particularly also, the Computational Intelligence Techniques were further developed. Cognitive Engineering or Cognitive Systems Engineering (Rasmussen, Pejtersen, and Goodstein, 1994), or Cognitive Science Approaches in general, appeared in the middle of the 1980s and continued to progress until today. Task analyses became cognitive task analyses to include also the human thinking behind the observable activities (Vicente, 1999). Models of human information processing were developed with search strategies, for example with hierarchical activities. The early Rasmussen model of skill-based, rule-based, and knowledge-based behaviour was a predecessor of this development (Rasmussen, 1976, 1986). Also, mental models have been of large interest in the domains of human-machine systems as well as of human-computer interaction. With further computerization and improvement of automation – even fostered through these developments, the interest in human errors (Reason, 1990), human reliability, and risk engineering became more prominent.

Later on in the era of 1985 – 2000, a development towards Multimodal Interaction and Cooperation occurred. There was a kind of over-visualization through the very intense use of computer graphics. Thus, it came to a certain visual overload in many application domains. The idea has been, therefore, to rejoin all sensory modalities in some way, particularly the most important ones, vision and audition – and the third important one, touch with haptic interfaces (Borys and Johannsen, 1997). Smell, balance, and proprioception are also important but less important than vision, audition, and touch. On the technological side, the continued development of computer graphics and video technologies led to the multimedia idea of combining these technologies further with audio technologies for music, sound, and speech. In addition, haptics, vibrations, and also olfactory devices, to a lesser degree, belong to the multimedia technologies. These technologies are the bases for developing multimodal interaction and cooperation for human-machine systems (Johannsen, 1997). The domain of virtual reality belongs here, too, and was partially developed within the human-machine systems field, partially besides, dealing with tele-presence and tele-action. Further, there are situations of immersion and pervasion. Also, the possibility of using wearable computing exists.

3. From Car Driving to Music

After outlining the historical eras until 2000, a brief overview on some application domains from Car Driving even up to Music indicates how much several of the developments described before are now

---

[9] Laboratoire d'Automatique Industrielle et Humaine

[10] Laboratoire d'Automatique, de Mécanique et d'Informatique industrielles et Humaines

belonging together or are carried out in parallel. When it comes to applications, even classical domains such as manual control became of new interest because they are, of course, still existing in car driving. The transdisciplinarity increased beyond multi- and interdisciplinarity in the last years. The following examples refer particularly to the works in the research group of this author.

Taking the example of car driving, it can be seen that manual and supervisory control are more necessary than before because new systems have been included into modern cars. It is not only the process of manual control but also the research interest in manual control has been revitalized. The area of manual control had to be revisited particularly also for haptic devices, etc. Decision making, problem solving, and communication tasks are involved in car driving, and the problems of awareness in high dense traffic situations, the possibilities of assistance, and the questions after responsibility have become more prominent. Also, multimodal interaction has finally made its way into car driving scenarios, into car cockpits: haptic devices and sound are used in addition to vision more and more. A few more details will be given below. Then, an overview follows on the evolutionary optimization of human-machine interfaces where a mix of technologies from several fields has been applied, too. Altogether, Control, Cognition, and also Emotion – affective computing and emotional interfaces – require to be more considered in coexistence for new designs and applications. Finally, it is enlightening to go beyond the more traditional engineering fields and discuss how much we can learn from music for supervisory and multi-agent control as well as for sound design and auditory displays.

3.1 Car Driving

The multi-level structure of car driving is illustrated in Fig. 5 (Johannsen, 2006b). The vehicle with longitudinal and lateral dynamics and the environment with the transport task and particularly the road, the driving environment, the traffic situation, etc. are shown. Human control in the broader sense and, thus, the activities of the driver are structured into three levels, the navigation, the guidance and the stabilization levels. On the navigational level, positioning and planning (time planning, speed planning, route planning, and course planning) are carried out. The course level deals with drives control in the longitudinal axis and detailed planning, trajectory tracking, and evasion in the lateral control loops. The longitudinal and lateral stabilizations loops follow as the inner control loops. All these are cascaded control loops. There are several possibilities for aiding the driver's tasks in all three levels. One way of looking at the car driving situation is still to observe the manual control tasks but, beyond, we have to look at the different interactions with new technologies.

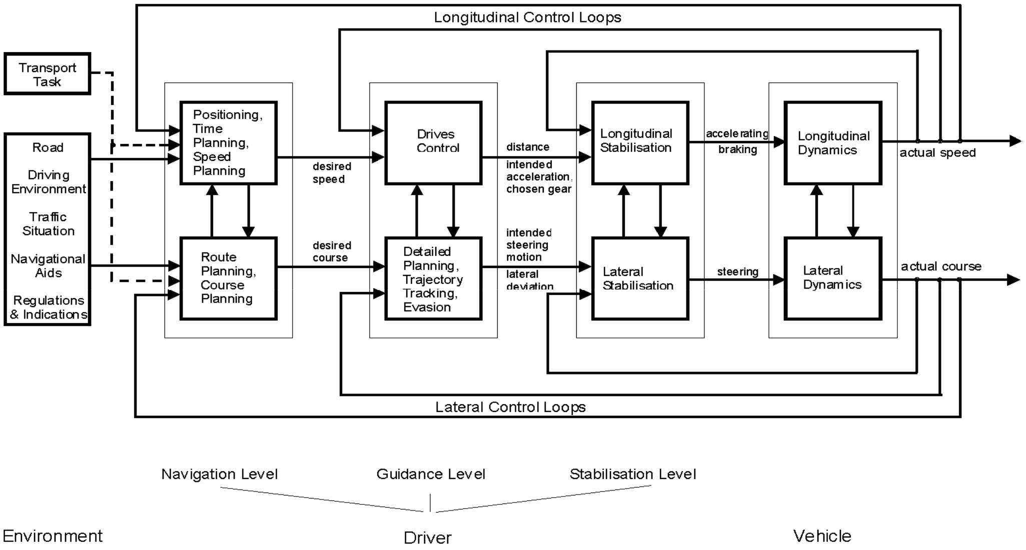


Figure 5. Multi-Level Structure of Car Driving (after Johannsen, 2006b).

An example for traditional manual control is shown in Fig. 6. This concerns the lateral dynamics and a two-level driver model for lateral control (Donges, 1978). One of the two levels describes anticipatory, open loop control where the desired curvature of the road is the input variable. The second level comprises compensatory control with three parallel processes for lateral deviation, yaw angle failure, and actual curvature compensation. This lateral control is very tough for assistance systems.

An overview on driver assistance systems has been proposed by Naab (2000). As shown in Fig. 7, traffic information is important for situation analysis, warning systems go up to situation assessment, and navigation further on to action selection. Then, new driver assistance systems include heading control and adaptive cruise control. They allow action execution to a certain degree. Automatic driving is far in the future, still maybe even more far away than 10 years ago. In the European Prometheus project where all European car manufacturers participated, there was a large enthusiasm, about ten years ago, that we can automate almost everything. Now with all the efforts, the expectations are much lower. We can do much, Adaptive Cruise Control is coming, but Heading Control, for example, is still very tough. It works in well structured situations but because the traffic environment is so complex and so difficult – and humans have so nice capabilities to quickly analyze the traffic environment – it will need several more years to improve heading control further.

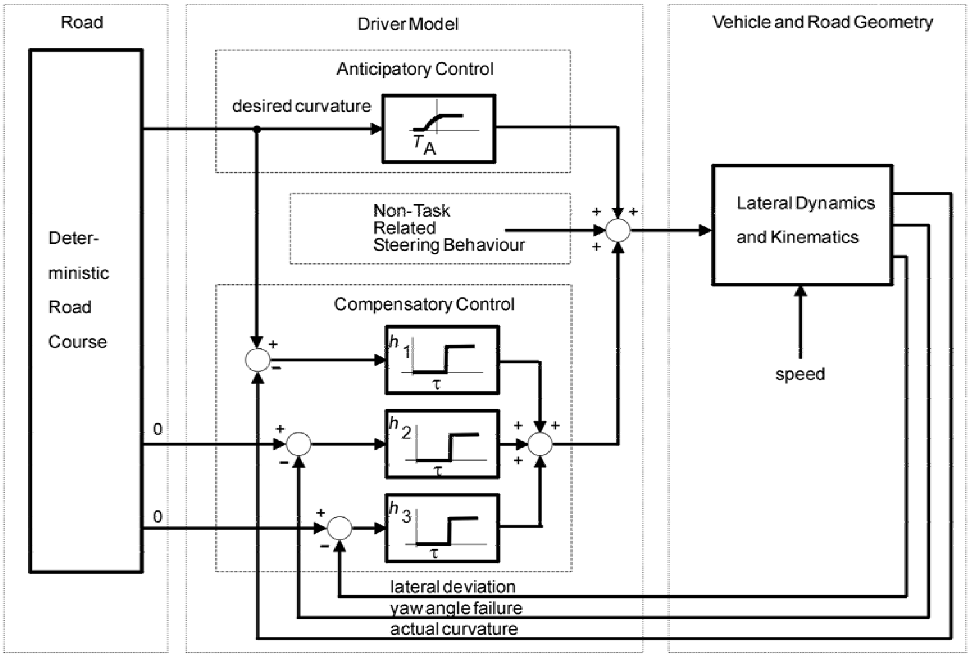


Figure 6. Two-Level Driver Model for Lateral Control (after Donges, 1978).

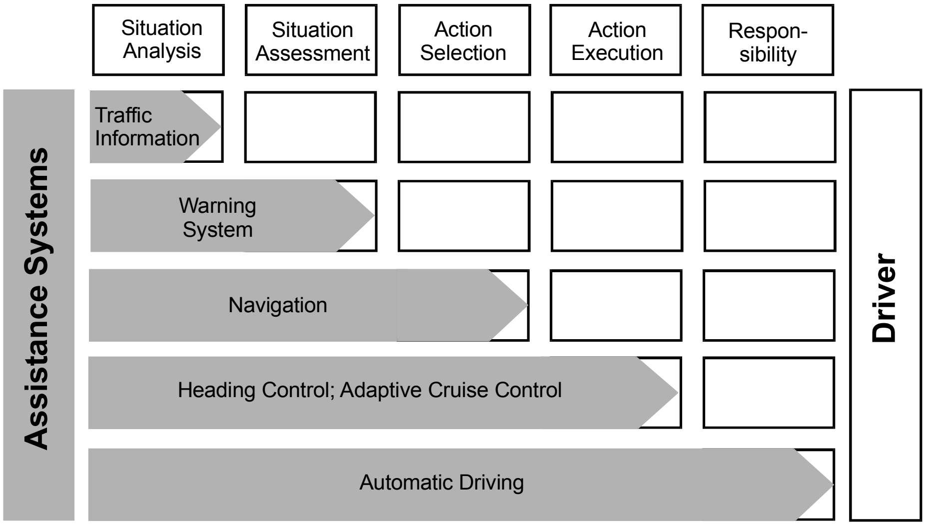
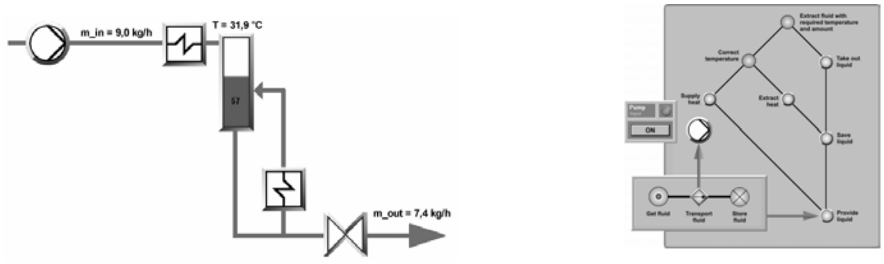


Figure 7. Degrees of Automation in Automotive Control (after Naab, 2000).

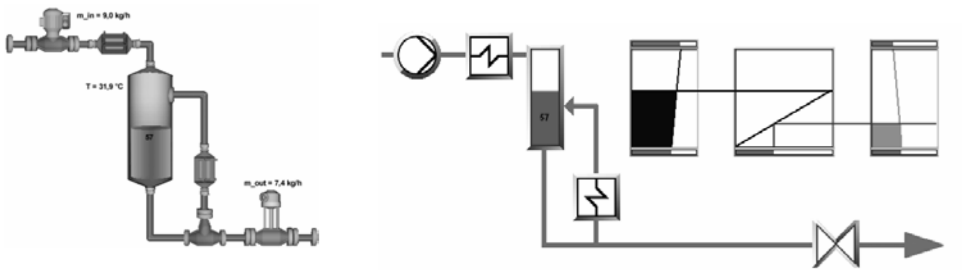
3.2 Evolutionary Optimization of Visual Displays

The application of evolutionary algorithms will be discussed briefly in the following. The doctoral dissertation of Andreas Völkel used interactive genetic algorithms for combining four different kinds of visualizations in the human-machine interface for a mixture process (Völkel, 2003, 2005). In Fig. 8, only a certain sub-part of this system is visualized, first the Topological, the standard view on the system, then the Multilevel Flow Modelling view with flow structures and decision hierarchies (Lind, 1990), further the Virtual 3D-Process visualization (Wittenberg, 2000) which is more a kind of photo-realistic visualization with the possibility to look into subsystems, and finally, the Ecological Interface Design by Vicente (Vicente and Rasmussen, 1990).



Topological View (TOP)

Multilevel Flow Modelling (MFM)
Lind (1990)



Virtual 3D-Process Visualization
Wittenberg (2000)

Ecological Interface Design (EID)
Vicente (1990)

Figure 8. Visual Display Designs with Genetic Algorithms (after Völkel, 2003).

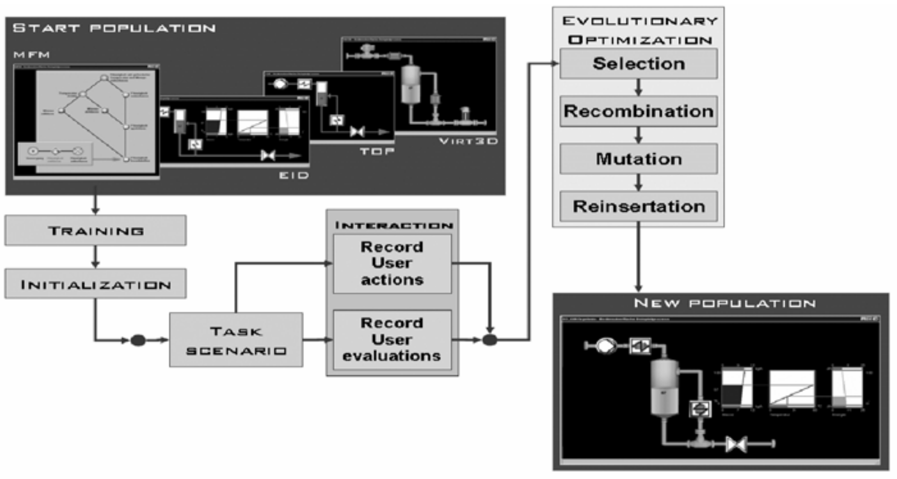


Figure 9. Structure of Evolutionary Optimization of Graphical User Interfaces (from Völkel, 2003).

The idea of using evolutionary optimization is to observe actions and information which are needed and, then, have an evolutionary optimization doing the redesign task based on such objective information from actions and information to the human, as well as subjective evaluations of the users. The structure of the algorithm and the process of the optimization can be seen in Fig. 9. The procedure comprehends starting the population of the four different visualizations, a certain training phase, and the initialization. Then for several task scenarios, the user actions are recorded as well as the subjective user evaluations. The evolutionary optimization uses similar phases as the biological evolution: selection, recombination, mutation, and reinsertation. At the end, new populations are created. The example in Fig. 9 (bottom right) shows a combination of topological, photo-realistic 3-D, and Ecological Interface Design views.

3.3 Music and Auditory Displays

The comparison between engineering and music systems is demonstrated with Fig. 10 (Johannsen, 2002). On top, the engineering system can be seen with operational engineers, human-interactive computers, task-interactive computers, and technical process units. In the lower part of the boxes, the music application is indicated with a conductor of an orchestra, part leaders, musicians, and the orchestra instruments or – with electronic music – also sound synthesizers. In a way, this is the supervisory control structure with process-near task-interactive musicians interacting with orchestra instruments, and task-interactive computers interacting with technical process units. Further components are a human-interactive entity – either a coordinating computer or the part leaders of the different instrument groups – and the human supervisor who gives control inputs but also supervises what is going on – on the basis of goals, work assignments or the score. The important difference between the engineering and the music cases is that many more internal feedback loops exist in the music situation. Thus, a much more flexible structure prevails in the music application than in the engineering case – from which we certainly can learn.

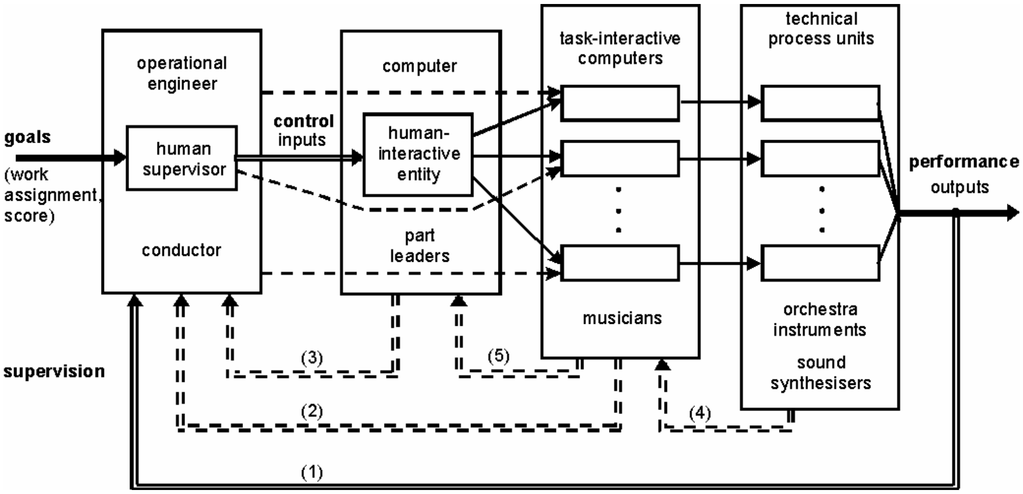


Figure 10. Human Supervision and Control in Engineering and Music Systems (from Johannsen, 2002).

If we look at this in more detail, we can see that timing is important in music, very much so, but also in engineering, in real-time control and supervision. The representation of time has also been considered in control engineering very much. Several time scales in parallel and synchronization are important. In music, the mental imagination, anticipation and, also, gestural control have more importance, but they are underway to move also more into the engineering field. Situations in control like leader-follower strategies have been investigated; conductor – part-leader – musician interaction is something similar. In both fields, similar developments can be observed. The supervisor often can be looked at just as an initiator or coordinator. Altogether, the question exists whether we observe more a multi-agent systems organization in music rather than hierarchical supervisory control. Certainly, communication needs exist between all these different agents and, also, shifting responsibilities between all of them. Some of the part-leaders, for example, can also take over the lead for an orchestra, even to the extent that a conductor is not necessary, at least for a small orchestra.

This suggests to looking at different work organizations. In music, the work organization seems to be more flexible, adaptive, and self-organizing. Several research groups in the field of human-machine systems have also started to work into this direction. This will increase more in the future. With multi-agent systems organizations, various levels of responsibility, autonomy, and collaboration occur. Also, sharing and shifting responsibilities and initiatives can be observed. This may correspond with different degrees of interaction, cooperation and, as it is sometimes called, embodiment between different subsystems. Altogether, a kind of mixed Supervisory & Multi-Agent control organization seems to be the appropriate description for future human-machine systems.

Other applications of music from which the engineering field can learn are the aspects of musical expression as well as sound design and the design of auditory displays. Musical expression can be seen as a particular model for engineering applications, in situations where we look at emotional interfaces, which is a new subfield in computer science today. Two international activities can be mentioned here. One is the annual conference series on New Interfaces for Musical Expression – NIME[11]; the last conference was held in June 2007 in New York, the seventh one. The other activity is a European network, a particular European COST Action on Gesture CONtrolled Audio Systems – ConGAS[12]**.**

Sound design is an artistic as well as a technical activity and deals with creating or using music, artificial and natural sounds. Often, it seems to be appropriate to do some kind of natural sound post-processing for certain engineering applications. Altogether, sound effect processing belongs here to come up with new sound patches which may be of interest for specific application domains.

The field of auditory displays goes a bit further and is more application-oriented in the way that sound symbols, sometimes also called earcons in analogy to icons, are developed with a dedicated meaning – a dedicated meaning for system states or particular situations, warning or alarming information or even information for supervision and control. Parameters for auditory displays can be melody, rhythm, timbre or sound colour, as well as the frequency composition of the different sub-items of the sounds in the auditory display.

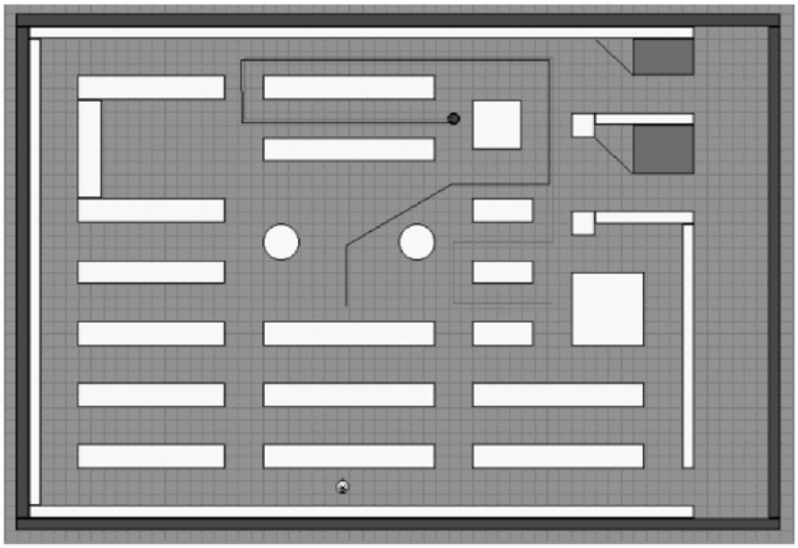


Figure 11. Sound Tracks of Mobile Robot Trajectories and States in a Supermarket (from Johannsen, 2004).

A brief example presents a study which was carried out a few years ago and was published in the Proceedings of the IEEE (Johannsen, 2004). This deals with the developments and the creation of a sound track for mobile robots and indicates their intended trajectory and some overlaid robot states in a supermarket scenario. Here, sounds for eight directions – Left, Left-Up, Down-Right, etc. – have been developed, and overlaid sounds are created for Heavy Load, Waiting, Low Battery, and Near Obstacle. In the example of Fig. 11, the first movement of the robot means to go Left, then a Turning sound can be heard, further going Up which is a melody upwards, then a Turning sound, going Right is a rhythm of a long-short-short sound, then the same again but with an overlay of the Heavy Load sound, then a Turning sound, etc. Musicians and non-musicians participated in the experimental study with much success.

---

[11] International Conference on New Interfaces for Musical Expression — www.nime.org

[12] European COST Action on Gesture CONtrolled Audio Systems — www.cost287.org

4. Future Perspectives

After having outlined the Historical Eras and, then, shown the diverse spectrum of applications from Car Driving to Music, some future perspectives are indicated in the following.

Human-cantered automation is already an important area since several years and will continue to deal with safety, human error, and risk management. Supervision, awareness, and trust are important issues of research, already over the last years but will continue to be important – particularly the areas of awareness and trust in automotive systems. The combination of investigating performance and workload always gets new impetus for the field and needs to be revisited again and again.

Decision aiding should be prospective and, in addition, needs to be corrective, more flexible, and more cooperative. New possibilities for decision aids and decision support systems are necessary in the future. The multimodal presentations will become more developed, more integrative in the future – this is at least my expectation – and dialogues, hopefully, much more transparent in all kinds of application domains and task situations. Functional representations behind the visual or auditory presentations should be better understood in human-machine interactions as well. We are on this way already since such developments like the multiflow-modeling or ecological interface designs have been created.

Altogether, the time of separating between human-machine systems, human-robot communication, and human-computer interaction – which were never completely separated – is over. We need to work towards a coherent Human-Machine Systems Science to establish the field even better for the future because it is much needed in all kinds of application domains.

REFERENCES

1. BORYS, B.-B., JOHANNSEN, G., **An Experimental Multimedia Process Control Room**, In Proc. Annual Conference 1997: Human Factors and Ergonomics Society Europe Chapter, Advances in Multimedia and Simulation, Bochum, 1997, pp. 276 – 289.
2. DONGES, E., **A Two-level Model of Driver Steering Behavior**, Human Factors, 20, 1978, pp. 691 – 707.
3. FERRELL, W.R., SHERIDAN, T. B., **Supervisory control of remote manipulation**, IEEE Spectrum, 4 (10), 1967, pp. 81 – 88.
4. JOHANNSEN, G., **Mensch-Maschine-Systeme** (Human-Machine Systems; in German), Berlin: Springer, 1993.
5. JOHANNSEN, G., **Computer-supported Human-machine Interfaces**, Journal of the Society of Instrument and Control Engineers (SICE) of Japan, 34, 1995, pp. 213 – 220.
6. JOHANNSEN, G., **Cooperative Human-machine Interfaces for Plant-wide Control and Communication,** In J.J. Gertler (Ed.), Annual Reviews in Control, 21, Oxford: Pergamon, Elsevier Science, 1997, pp. 159 – 170
7. JOHANNSEN, G., **Human Supervision and Control in Engineering and Music – Foundations and Transdisciplinary Views**, In G. Johannsen and G. De Poli (Eds.), Human Supervision and Control in Engineering and Music. Special Issue, Journal of New Music Research, 31 (3), 2002, pp. 179 – 190.
8. JOHANNSEN, G., **Auditory Displays in Human-machine Interfaces**, In G. Johannsen (Ed.), Engineering and Music – Supervisory Control and Auditory Communication. Special Issue, Proceedings of the IEEE, 92 (4), 2004, pp. 742 – 758.
9. JOHANNSEN, G., **Historical Views on Human Engineering: From Control to Cognition** (invited paper), In A. Amditis (Ed.), Proc. 24th European Annual Conf. Human Decision Making and Manual Control (EAM2005); CD-ROM. Athens: Institute of Communication and Computer Systems.
10. JOHANNSEN, G., **Historical Views on Human Engineering – From Control to Cognition**, In D. Söffker, W. Luther, and E. Ahle (Eds.), Guidance and Control of Autonomous Systems (Proc. DAAD-German Summer Academy, Duisburg, 2005); Overview and Selected Viewgraphs. Berlin: Logos Verlag, 2006a, pp. 1 – 6.

11. JOHANNSEN, G., **Fahrzeugführung und Assistenzsysteme** (Vehicular Guidance and Assistance Systems; in German), In B. Zimolong and U. Konradt (Eds.), Ingenieurpsychologie, Enzyklopädie der Psychologie, Band D/III/2, 2nd Edition. Göttingen: Verlag für Psychologie, Hogrefe, 2006b, pp. 737 – 775.
12. JOHANNSEN, G., RIJNSDORP, J.E. (Eds.), **Analysis, Design, and Evaluation of Man-Machine Systems** (Proc. IFAC/IFIP/IFORS/IEA Conf. 1982). Oxford: Pergamon Press, 1983.
13. KLEINMAN, D.L., BARON, S., LEVISON, W.H., **An Optimal Control Model of Human Response. Part 1: Theory and Validation**, Automatica, 6, 1970, pp. 357 – 369.
14. LIND, M., **Representing Goals and Functions of Complex Systems – An Introduction to Multilevel Flow Modelling**, Technical Report 90-D-381, Institute of Automatic Control Systems, Technical University of Denmark, 1990.
15. MCRUER, D.T., **Human Dynamics in Man-machine Systems**, Automatica, 16, 1980, pp. 237 – 253.
16. MCRUER, D.T., JEX, H.R., **A Review of Quasi-linear Pilot Models**, IEEE Transactions on Human Factors in Electronics, **HFE-8**, 1967, pp. 231 – 249.
17. MCRUER, D.T., WEIR, D.H., **Theory of Manual Vehicular Control**, Ergonomics, 12, 1969, pp. 599 – 633.
18. MILLOT, P., **Supervision des procédés automatisés et ergonomie**, Paris: Editions Hermès, 1988.
19. NAAB, K., **Automatisierung bei der Fahrzeugführung im Straßenverkehr**, Automatisierungstechnik, 48, 2000, pp. 211 – 223.
20. NICHOLS, J.A., SCHNEIDER, M.L. (Eds.), **Proceedings of the 1982 SIGCHI Conference on Human Factors in Computing Systems**, Gaithersburg, Maryland, New York: ACM Press, 1982.
21. RASMUSSEN, J., **Outlines of a Hybrid Model of the Process Plant Operator**, In T.B. Sheridan and G. Johannsen (Eds.), Monitoring Behavior and Supervisory Control. New York: Plenum Press, 1976, pp. 371-381.
22. RASMUSSEN, J., **Information Processing and Human-Machine Interaction**, New York: North Holland, 1986.
23. RASMUSSEN, J., PEJTERSEN, A.M., GOODSTEIN, L.P., **Cognitive Systems Engineering**, New York: Wiley, 1994.
24. REASON, J., **Human Error**, Cambridge: Cambridge University Press, 1990.
25. ROSSON, M.B., GILMORE, D., et al. (Eds.), **Conference on Human Factors in Computing Systems** (Proc. ACM SIGCHI Conf., San Jose, CA, 28 April – 3 May 2007), New York: ACM Press, 2007.
26. SANDERS, M.S., MCCORMICK, E.J., **Human Factors in Engineering and Design**, 7th Edition (first edition appeared 1957), New York: McGraw-Hill, 1993.
27. SHERIDAN, T.B., **Forty-five Years of Man-machine Systems: History and Trends**, In G. Mancini, G. Johannsen, and L. Mårtensson (Eds.), Analysis, Design, and Evaluation of Man-Machine Systems (Proc. IFAC/IFIP/IFORS/IEA Conf. 1985). Oxford: Pergamon Press, 1986, pp. 1 – 9.
28. SHERIDAN, T.B., **Telerobotics**, Automation, and Human Supervisory Control, Cambridge, MA: The MIT Press, 1992.
29. SHERIDAN, T.B., **Humans and Automation: System Design and Research Issues**, New York: Wiley, 2002.
30. SHERIDAN, T.B., FERRELL, W.R., **Man-Machine Systems: Information, Control, and Decision Models of Human Performance**, Cambridge, MA: The MIT Press, 1974.
31. SHERIDAN, T.B., JOHANNSEN, G. (Eds.), **Monitoring Behavior and Supervisory Control**, New York: Plenum Press, 1976.
32. TAYLOR, F.W., **The Principles of Scientific Management**, New York: Harper Bros., 1911.
33. VICENTE, K.J., **Cognitive Work Analysis**, Mahwah, NJ: Lawrence Erlbaum, 1999.

34. VICENTE, K.J., RASMUSSEN, J., **The Ecology of Human-machine Systems II: Mediating "Direct Perception" in Complex Work Domains,** Ecological Psychology, 2, 1990, pp. 207 – 249.

35. VÖLKEL, A., **Evolutionary Optimization of Graphical Human-machine Interfaces for Controlling Technical Processes**, In G.C. van der Veer and J.F. Hoorn (Eds.), Cognition and Collaboration – Distributed Cognition in Complex Processes. European Association of Cognitive Ergonomics (EACE). Amsterdam, 2003, pp. 137 – 143.

36. VÖLKEL, A., **Evolutionäre Optimierung von Mensch-Maschine-Schnittstellen**, Doctoral Dissertation, University of Kassel, Systems Engineering and Human-Machine Systems. Berlin: Logos Verlag, 2005.

37. WITTENBERG, C., **Virtuelle Prozeßvisualisierung am Beispiel eines verfahrenstechnischen Prozesses,** Doctoral Dissertation, University of Kassel, Systems Engineering and Human-Machine Systems, 2000.

38. YOON, W.C. (Ed.), **Analysis, Design, and Evaluation of Human-Machine Systems** (Proc. 10th IFAC/IFIP/IFORS/IEA Symposium, Seoul, Sept. 4–6, Oxford: Pergamon, Elsevier Science, 2007.