Information Ergonomics

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1 Categorizing and Definitions

1.1 Micro and Macro Ergonomics

"Ergonomics" is a multi-disciplinary science which uses basic knowledge from Human Science, Engineering Science, and Economic and Social Science. It does comprise occupational medicine, industrial psychology, industrial pedagogic, working-technique and industrial law as well as industrial sociology. All of these sciences, from their different points of view, deal with human work and therefore represent an aspect of this science. With regard to feasibility, this basic knowledge is summarized in so-called praxeologies (see Fig. 1). The more economic-academically and social-academically oriented of them is the "macro ergonomics", which provides rules for the creation of organization, company groups and study groups. The more engineering oriented "micro ergonomics" gives rules for the technical design of workplaces and working means. The latter refers at first in narrower sense to the interaction between person and machine. However, in both cases the special focus of the research is directed upon the individual person and his experience of the situation in the workplace what represents the ergonomic specialty compared with the other science disciplines which argue with similar contents.

The central object of the ergonomics is to improve by analysis of tasks, of environment and of human–machine-interaction the efficiency of the whole working system as well as to the decrease of the charges having an effect on the working person (Schmidtke 1993).

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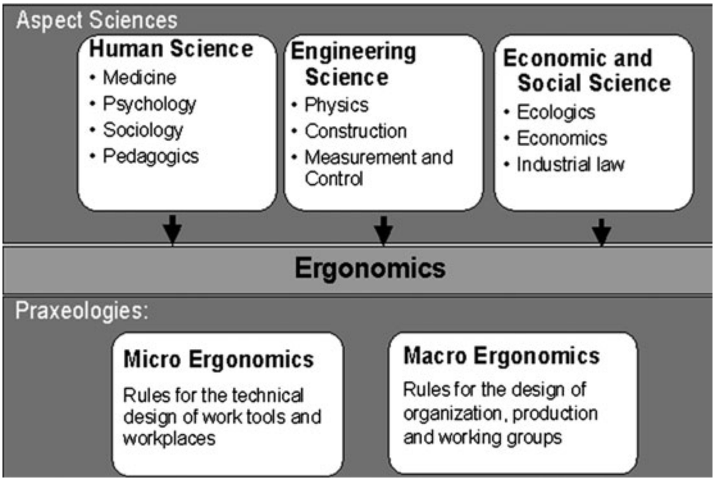


Fig. 1 Ergonomics and their disciplines

1.2 Application Fields of Ergonomics

Today it has established as meaningful to divide also ergonomics after its areas of application. Thus it can be distinguished especially between product ergonomics and production ergonomics:

- *Product ergonomics*
  The priority aim of product ergonomics is to offer a very user-friendly utensil for an in principle unknown user. Therefore, for the development of such products it is important to know the variability of the users with respect on their anthropometric properties as well as their cognitive qualities and to consider this during the designing process. An actual and new field of research of the product ergonomics is the scientific question what is the meaning of *comfort feeling*.
- *Production ergonomics*
  The matter of production ergonomics is to create human adapted working places in production and service companies. Here is the aim to reduce the load of the employee and to optimize at the same time the performance. In contrast to the case of product ergonomics the employees are ordinarily known and it can and must be considered individually their needs. According to all experience the acceptance of ergonomic measures is only guaranteed in production processes if they are carried out in co-operation with the employee.

As the above described methods of the ergonomics are applied as with product as with production ergonomics and because often the "product" of one manufacturer is "working means" of the other, an exact separation is not possible between these both areas of application practically, particularly as in both areas the same scientific methods and conversion procedures are used.

Areas of application of primary importance, in which today systematically ergonomic development is operated, are the range of aviation (special cockpit design of the airplanes, design of the radar controller jobs), the vehicle design (passenger car and truck: Cockpit design; anthropometric design of the interiors, so-called packaging; design of new information means, by which security, comfort and individual mobility are to be improved), design of control rooms (chemical plants, power stations; here above all aspects of the human reliability play an important role) and offices (organization of screens, office chairs, the total arrangement of workstations, software ergonomics). Also the development of well understandable manuals can be assigned to the area of ergonomics. A further special field of ergonomics is the research of limit values for working under extreme conditions like extreme spatial tightness, cold weather, heat, excess pressure, extreme accelerations, weightlessness, disaster control operation, etc.

2 Object of Ergonomic Research

2.1 What Is Work?

If within the scope of ergonomic design the work and the working means – it is the machine – should be designed appropriate for human properties it is to be answered first the question what should be understood by work in this connection. Work and work content are certainly determined on the one hand by the working task, on the other hand, however, also essentially by the qualities of the tools which are developed for the increase of the working efficiency or to the relief of the worker. Work is divided traditionally in physical and mental work. The technical development allows expecting that furthermore a substitution of physical work by suitable machines takes place and with it a far-reaching shift of physical work to mental work.

With view on manual work the investigations of Taylor and his co-worker Gilbreth play a basic role. The systems of predetermined times are based on their works which dismantle manual works in activity elements and assign to these times as a function of the accompanying circumstances. In general more than 85% of all activities can be described by the working cycle consisting of the activity elements "reach", "grasp", "move", "position", "fit" and "release" (see Fig. 2).

As can be shown, this work beside the physical aspect of the "Move" has essentially information changing character (Bubb 1987). Already in 1936 Turing has carried out a general description of such processes of information changing (see Fig. 3): The person respectively the information processing system perceives a symbol, is able in the next step to extinguish this symbol respectively to headline it and shifts now in the third step the neighbouring, in its arrangement necessarily not recognized symbol to the place of the original symbol. This process marks an ordering process. It is easy to understand that the activity elements "reach", "grasp" and "move" can

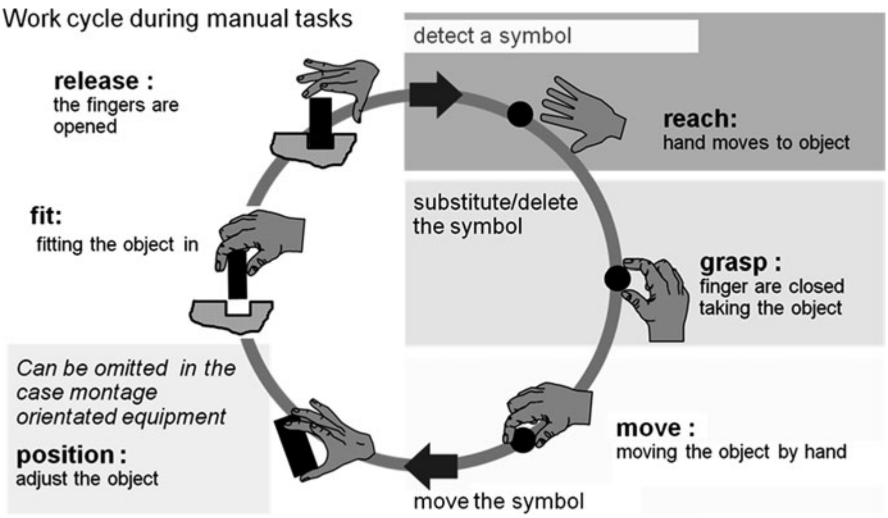


Fig. 2 Motion cycle in connection with manual activities

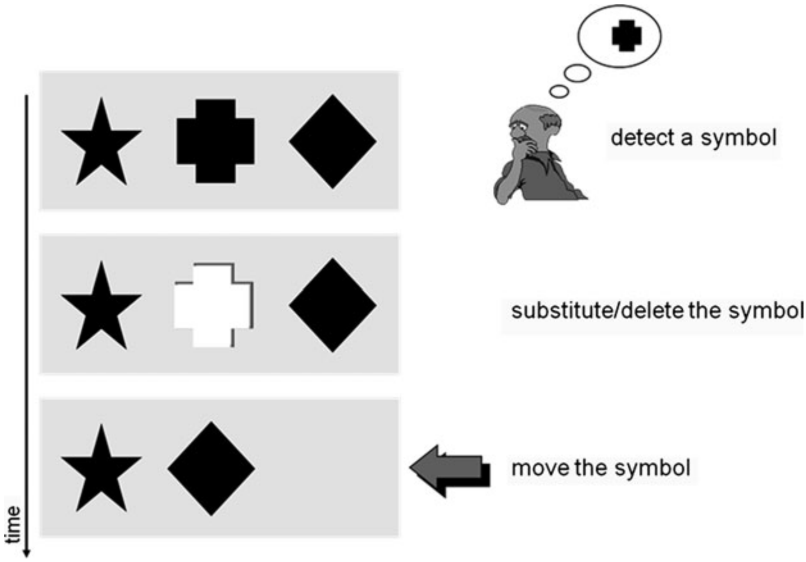


Fig. 3 The Turing machine as a model of thinking processes – elementary basics of ordering

be assigned to these three Turing elements. The ordering process of an assembly is closed with these three activity elements. The further activity elements are obviously only necessary to fix the new order. They can be partially or also completely cancelled by a favorable "rational" design of the working place (e.g., "position").

Also pure mental activities are to be seen under this aspect of "ordering". Also in this case it is principally possible to separate the substantially order producing elements of work from such that have only fixing or preparing character. An essential aspect of ergonomic design consists in recognizing unnecessary working steps and in removing or in simplifying it at least by technical design.

In generalization of the considerations shown here and according to the scientific concept of information after which information is a measure of the divergence of the probable autonomously, i.e. "naturally" appearing state (information = negentropy), can be concluded that every human work shows an ordering process, by which against the natural trend of the increase of the entropy (= decrease of negentropy or information) an artificial human produced state is created (Bubb 2006). By producing such an ordering energy turnover is always implied for the supply of the necessary movement. This energy turnover can be raised directly by the human activity (physical work) or by a machine, which must be operated, however (mental "operating work").

The here presented scientifically oriented working concept goes out from effects visible to the outside, i.e. from an objective point of view. After that work is production of an artificial human created order, i.e. the production of a work in terms of goods and service (Hilf 1976). The humanities-related working concept characterizes on the other hand the subjective experience of the work (Luczak 1998). This is frequently characterized by "trouble and plague", however, can be also depending on the internal settings a cause for an increase of self-esteem and subjectively positively experienced satisfaction. For a comprehensive working analysis both aspects are to be considered. The demand of order production characterizes the (in principle objectively detectable) load, the subjective experience the strain depending on individual qualities, abilities and settings.

Basis of every Man Machine System (MMS) design is therefore the flow of information which conveys the task that should be accomplished with the system transfers in the result. This human machine interaction can be illustrated especially well by means of the metaphor of the control circuit: the human operator transforms the information given by the task into a control element position which is conveyed by the working principle of the machine in the output information, the result. Normally the possibility consists to compare task and result with each other and to intervene with a not accepted deviation correcting in the process. This process can be influenced by circumstances which deal nothing with this real task-related flow of information. They are designated in this context "environment" or "environmental factors" (see Fig. 4). The degree of the relationship of the result R and the task T represents the working quality Q:

$$Q = \frac{R}{T} \tag{1}$$

The working performance P is the working quality achieved per time t (Schmidtke 1993):

$$P = \frac{Q}{t} \tag{2}$$

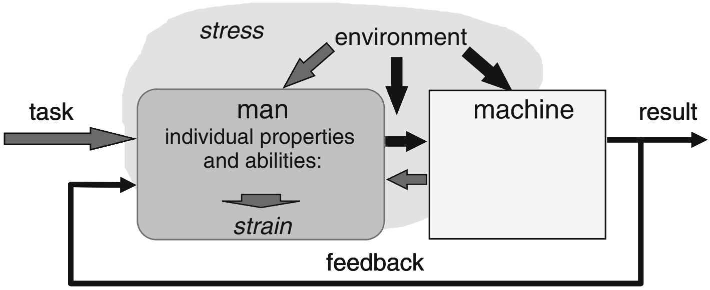


Fig. 4 Structural scheme of human work

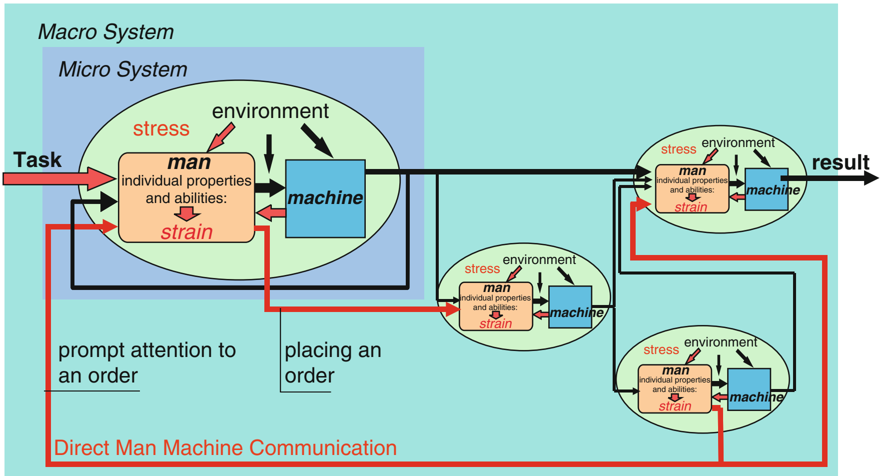


Fig. 5 Information flow in a macro system consisting of several single human machine systems

The aim of ergonomic design is to reach an optimization of the performance by an adaptation of the working means (= machine) and the working environment to the human operator.

If one extends the Fig. 4 by the possibility of the operator to prompt attention to an order and to place an order to other, the micro system of the simple human machine system can be extended to the macro system of complicated equipment (Fig. 5).

In any case, the individual human performance during accomplishing his work is influenced by the so-called external performance shaping factors and by the so-called internal performance shaping factors (see Fig. 6). It is a job of the management to create the requirements for an optimum performance application of the operator by the design of the external conditions. Thus the connection is produced between the ranges of Micro Ergonomics and Macro Ergonomics.

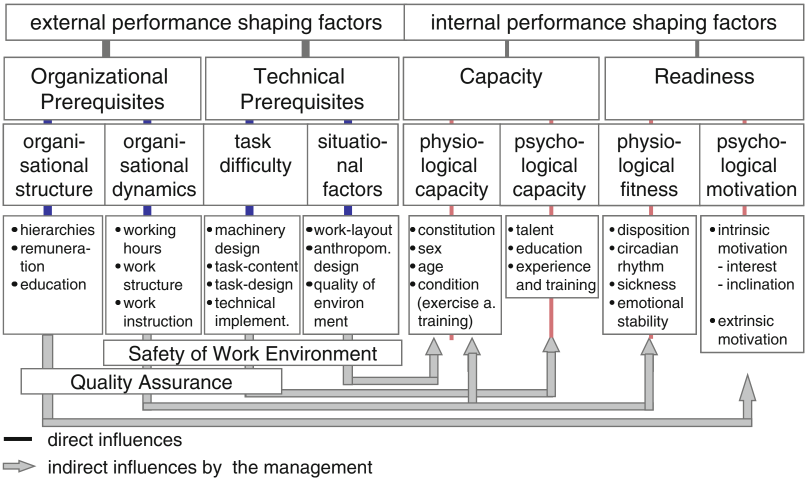


Fig. 6 The working performance influencing preconditions

3 The Position of Information Ergonomics in the Field of the Science of Work

3.1 System Ergonomics

From the preceding discussion the basic approach becomes visible to understand every working process as an information change. As the operator is integrated in a – if necessary complicated – system, the comprehensive consideration of the total system is of prominent meaning for the design of the work appropriate for human worker. This is designated in general *system ergonomics* (Hoyos 1974; Döring 1986; Luczak 1998; Kraiss 1989; Bubb 2003a,b). Within the scope of the system ergonomics the information flow is investigated that result from the integration of the human operator in the man machine system. The design produces the optimization of this information flow. In order to achieve it two destination directions are of importance that excludes them mutually by no means. In order to reach the aim in both cases often the same measures can be used: On the one hand, the system can be optimized for the purposes of the working performance as defined above and on the other hand for the purposes of the system reliability. In the first case it is a matter of raising the effectiveness and the accuracy of the system, i.e. the quality achieved per time unit. The applied methods are taken over largely from the control theory. Essential consideration objects are the dynamic properties of the system for whose description particularly transitional function and frequency response are suited. In the second case it is the aim to receive the operational safety of the system or even to raise it, i.e. to minimize the probability for the fact that the system gets out of control. The applied methods are those of the probabilistic. In order to describe the interaction of the total system, the methods of the Boolean algebra are applied. For the appearance of failure probabilities or from mistakes probability distributions must be assumed. In particular the Human Error Probability (HEP) plays a role in this connection.

Design ranges of the human machine interface and the system ergonomics are related among other things to the working place, the working means, the working environment, the design of the operating sequence and the working organization as well as the human computer interface. Hereby the frame conditions (of design) are among other things:

– The working task,
– The external conditions,
– The technology of the human machine interface (MMI),
– The environmental conditions,
– Budget, and
– User's population (Kraiss 1989).

In the focus of the mentioned aims based on Schmidtke (1989) the following objects are to be mentioned:

– Functionality (adequate support of the coping of the problems),
– Usability (intelligibility for potential users),
– Reliability (error robustness, that is "less" operating errors are tolerated),
– Working safety (avoidance of health damages),
– Favorability of individuals (consideration and extension of the user's ability level).

Further aims are economic efficiency and environmental compatibility (Kraiss 1989).

With regard to the information change within the system – especially concerning the capturing of the task – one can make following differentiation from the point of the integrated individuals:

• The information of the task and in many cases also the result is received from the natural environment. This is, e.g., the case with the steering of land vehicles, where the necessary reactions are taken up visually from the natural environment that contains the traffic situation. The same is also valid for operating quick vessels and partly for operating airplanes during the start and in particular during the land approach. Another example is observing the executions and the action by workers in the assembly line. Many working processes – for example, in the craft range – are characterized by such "natural" information transmission.
• The information of the task or partial aspects of the task, the whole fulfillment of the task or certain measurable working conditions of the machines are given artificially by displays. In this case the optimization of the process refers not only to the interaction possibilities and the dynamics of the system, but substantially also to the display design that should be realized in such a way that contents and meanings of the processed information are reasonable for the person very

immediately. Because here the focus lies on the design of this information processed by a technical way, this special branch of the system ergonomics is designated often also *information ergonomics* (see below; Stein 2008). In this connection is to be mentioned the so-called "Augmented Reality (AR) technology" by which artificial generated information is superimposed to the natural environment. Different technologies are available for this. Fix mounted Head Up displays (HUD) in vehicles and with the head of the operator solidly connected Helmet Mounted Displays (HMD) are most common today. But also the methods of the holography or special laser technologies are discussed in this connection. By means of these optical principles it is possible for the operator to receive at the same time the natural environment and the artificially generated information.

The increasing mediatizing and informatizing given by the technical development let increase the importance of information ergonomics, as under the condition of the complex technology it becomes more and more necessary to provide the user with quick, unequivocal, and immediately understandable information (Stein 2008). Especially the safety demands in aviation offer a big challenge for application of information ergonomics.

3.2 Software Ergonomics

The professional life was changed very comprehensively by the introduction of the computer technology. If only rather easy logical linkages were possible with the traditional technology (e.g., mechanical realization of the basic arithmetical operations by means of engine-operated or hand-operated calculating machines respectively by means of the relay technology realized simple representations of the Boolean algebra in electric circuits), so by the computer technology demanding "mental processes" can be also copied now, decisions are made, complicated graphic representations are generated in real-time and much more. The similarity of computational information processing to that of the human operator, but also the indispensable stringent behavior of the computer pose quite specific problems to the user. The adaptation of program flows, of interventions in this, as well as the suitable representation of the results for the user has become an own branch of the ergonomics which is assigned by "*software ergonomics*". By it is understood the creation, analysis and evaluation of interactive computer systems (Luczak 1998; see also Volpert 1993; Zeidler and Zellner 1994). With the software ergonomics there stands the "human appropriate" design of user interfaces of a working system (among other things dialog technology, information representation), considering the task to be performed and the organizational context in the centre of the ergonomic interest (Bullinger 1990; Bullinger et al. 1987; Stein 2008).

On account of its meaning software-ergonomic demands are agreed effectually in European, as well as national laws, as well as partly on voluntariness to based standards. Beside different more generally held guidelines particularly the *DIN EN ISO 9241* – 110 and *DIN EN ISO 9241* – 303 is to be mentioned here.

Particularly the principles of the dialog design are highlighted here:

- *Task suitability*: A dialog is task appropriate if it supports the work of the user without unnecessary strain by the attributes of the dialog system.
- *Self-describability*: A dialog is self-descriptive if the user will be informed on demand about the scope of performance of the dialog system and if each single dialog step is direct intelligible.
- *Controllability*: A dialog is controllable if the user manages the dialog system and not the system the user.
- *Consistent with expectancy*: A dialog is functional if it does what the user expects out of his experience with previous work flow or user training.
- *Fault tolerance*: A dialog is fault-tolerant if in spite of faulty entries the intended working result can be reached with minimal or without correction.
- *Can be customized*: A dialog should be able to be adapted to the individual needs or preferences of the user.
- *Learnability*: A dialog i.e. easy to learn if the user is able to manipulate the system without reading help functions or documents.

3.3 Information Ergonomics

The technical development has led to the interlinking of the computers, assigned in the companies internal as “Intranet” and worldwide as “Internet”. In these networks in a unconceivable manner information is transported, processed and made available from the point of view of the user’s as good as detached from a material supporter (of course, if this is not correct actually!). The hypermedia organization of the information, the investigation of human search strategies, whose result is a requirement for the creation of search engines and again the technical representation of the so gained information, is a main object of the already mentioned *information ergonomics*. The concept information ergonomics is often shortened related to the creation of Internet-based information systems, here in special the navigation design. In the foreground here stands the support of search strategies (searching) which should lead fast to the required information. In addition, beside the support of searching by adequate search tools a support of the “rummaging” or “going with the tide” is also aimed in the cyberspace (Browsing; see Marchionini and Shneiderman 1988). This means that information systems must be designed in such a way that different navigation patterns and therefore not only purposeful actions are supported (see also Herczeg 1994). Consequently not only the not planned, but also the implied and interest-leaded action is considered. Thus the search is often based on a voluntary interest in information which can be used partly for professional as well as for private purposes. Competing information and theme areas are only one “click” nearest of each other. This requires, by means of media design to create an incentive (attraction) and to hold this for the period of use in order to avoid e.g., psychic tiredness, monotony and saturation and to allow states like “flow”.

After Stein and Müller (2003a, b) the goal of information ergonomics is the optimization of information retrieval which includes information search and selection (appraisal and decision making processes) as well as cognitive processing of text-, image-, sound- and video-based information of information systems. In this respect, information ergonomics comprises the analysis, evaluation and design of information systems, including the psychological components of the users (capabilities and preferences, etc.) as well as work tasks (information tasks) and working conditions (system and environmental conditions) with particular emphasis on the aspects of motivation, emotion and cognitive structure (content knowledge and media literacy). User motivation and emotion during information system access and retrieval processes are fields of investigation and analysis (Stein 2008).

On the part of the information system information retrieval is affected by the implemented information structure (organization and layout) and by the design and positioning of navigation aids as well as by information contents and their design. The exactness and swiftness of perception, and selection (appraisal and decision making) of information with regard to their pertinence to professional or private needs (information) on the part of the recipients primarily depends on text, image, sound, video design and structuring. This also applies to the quality of cognitive processing.

Information structure, content categories, navigation instruments, search functions, graphics/layout, links, text/language, image, sound and video design etc. represent levels of design. Design should enable the user to successfully perform information retrieval, appraisal and decision making, selection and cognitive processing within the scope of a work task or a self-selected goal within a reasonable period of time. In addition, the information system should be designed to enable the user to exceed his initial skill level with regard to his media literacy and expertise (Stein 2008).

Figure 7 shows the general structure of information ergonomics: It is the task of information system to transform the information system access into the application of information to a control task. The information system access is essentially influenced by the system, the task and the environmental conditions. These conditions define the necessary information retrieval. In order to design the information system and with it the information retrieval according to ergonomic demands the user with his information goals, his expectations, motivation, emotion knowledge and media literacy is to be considered essentially.

Thus seen information ergonomics represents a specialization of system ergonomics whereas especially such systems or system parts are considered in which the technical processing of the information dominates.

3.4 Communication Ergonomics

Whereas the information ergonomics refers partly substantially to the use of the Internet, the use of the Intranet belongs to the so-called *communication ergonomics*. Concerning this it must be highlighted that user's interfaces differ in the production area generally considerably from such in information systems. While Internet-based information systems are based as a rule on information tied up to links (hypermedia) which opens for their part a huge number of further information, by contrast as a rule user interfaces in the production area allow access on a high detailed, but limited thematic area. After Zülch (2001a) object of the communication ergonomics is to design the information exchange between human operator and technical system in such a way that the abilities, skills and needs of the operator are considered appropriately whereby the aim is to design user friendly economic courses, products, jobs and working environments. Hereby especially mental overloading or under loading should be avoided to achieve the best possible result of working (Zülch 2001a; Zülch Stowasser and Fischer 1999; Kahlisch 1998; Simon and Springer 1997). The communication ergonomics contain the "creation of use interfaces in the production range, evaluation of CIM interfaces, navigation in object-oriented data stores, creation of multimedia documents, and standard conformity tests" (Zülch 2001b). Concerning this all working places with screens are an object of the ergonomic interest.

3.5 Cognition Ergonomics

In the before mentioned areas of ergonomic research and application it is primarily about the information flow and less about the physical design of the working place. Information processing by the human operator makes demands for his cognitive abilities. That is the reason why the concept *"cognition ergonomics"* has also recently become the custom as a name for the areas described above.

3.6 Application Fields

The system-ergonomic design, respectively the application of information ergonomics is necessary because of the penetration of all technology with computer technology today in almost all scopes of work. Many devices of the daily life (remote control for electronic entertainment devices, electric washing machine, the entertainment system in cars, etc.) as well as electric tools, machine tools, like NC- and CNC-machines, robots in the production area, but in future also more and more in the household area are examples for this. In the context of company internal information systems a specific information management is necessary. A special attention is necessary here for the knowledge loss which is given by retired employees. It is expected to absorb this loss with computer based knowledge management systems. The progressing integration of the domestic entertainment media on the Internet makes necessary user-friendly information systems. Generally the Internet revolutionizes the accessibility and use of information and of libraries. In the supervision control centers for traffic engineering (e.g., traffic engineering for the urban traffic, air traffic controller, shipping pilot centrals), in the control centers of power plants, and chemical equipments the access to special computer programs occurs. The passengers of public transportation systems (in particular railway and air traffic) receive information about timetables as well as the tickets from computer-controlled machines. The control of the vehicles is supported more and more by so-called assistance systems. If for a long time the aviation has played here forerunners roll, such systems penetrate today more and more into the area of the privately used motor vehicles.

The enumeration of these application areas makes evident a difference between the users. While one can be compensate in the commercial range lacking ergonomic design of the interaction by suitable training and training programs, one must go out in the area of private use from the untrained and unskilled operator. There the highest ergonomic demands are made. The application of the rules which one achieves in this area will also bring in the commercial area advantages in form of more reliable and more efficient operation. Not at least this will lead to long-term reduction of costs.

4 The Object of Information Ergonomics

4.1 System Technological Basics

In general it can be ascertained: The application of system-theoretical principles to ergonomic questions is assigned by *"system ergonomics"*. The system theory itself has its origin in the information transfer technology (Wunsch 1985). It treats every considered complex of (natural) phenomena in principle according to the same basic scheme. The advantage of it is to be able to treat even the human operator in his interrelation with the technical environment with uniform methods.

By *system* is understood the totality of the necessary technical, organizational and/or other means that are necessary for the self paced fulfillment of a task complex. Every system can be thought composed of elements which interact to each other. The essential aspect of the system theory lies in the fact that the physical nature of the interaction is ignored (e.g., force, electric voltage/current, temperature, air or body sound, etc.) and only the information contained in it respectively the information change caused by the system is considered. In this connection by information is understood every deviation of the natural distribution of energy and matter, as already shown above. Practically the aimed information change can consist in the change of matter (task of the "machines") as well as in the change of energy (task of the "prime movers" or "energy production") as well as in the spatial change of energy/matter (task of the hoisting devices, conveying plants, pumps, fans, vehicles) or in the change of matter/energy distributions (task of the information-processing machines, as for example computer, data carrier, and so on). During his operation the human operator transmits information on the machine and provides in such a way for the fact that this manages the effects desired from him.

The desired change can only occur, as the system stands in information exchange with the so-called system environment (so-called "open system"). The system has therefore an input side ("input") by which from the environment information (i.e. energy or matter) on one or several channels is taken up and a output side ("output") by which the changed information on one or several channels is delivered. All effects which influence the desired process of the information change by the system are designated in this sense by "environment".

In order to get a more exact idea of the functions and effect mechanisms of the system, it is thought composed of *elements* and these elements stand with each other in the information exchange. The active relations of the elements are described by the *system structure*. The canals of information are shown graphically as arrows which mark therefore also the active direction of the information. Within such an effect structure the parts are called the elements which change the detailed information in typical manner. One distinguishes elements which connect information with each other or such elements which information distribute (convergence point, branching point, switch), and elements which change information according to a function and again those are separated, with which the time plays no role ("elements without memory"), from such with which the time plays a role ("elements with memory"). Elements with memory cause a system dynamic. As the human operator is always an "element with memory" in any case a human–machine-system has a dynamic that means its behavior is time dependent.

Under the shown aspect the machine as well as the human operator can be seen as a component of a *"human machine system"*. One can distinguish basically two manners of connection: A *serial connection* describes the case that the person takes up the information of the task, converts it in adequate manner and transfers it by the control elements on the machine. This changes – mostly under change of separately added energy – the input information in the deliberate result (so-called *active system*; e.g., car driving: the task lies in the design and lay-out of a road and in the situation presenting there, the result is the actual position of the vehicle on the street). Generally the operator can observe the result and derive new interventions by the control elements from the comparison with the task. It is a closed-loop *controlled* process. If, nevertheless, the time becomes too big between the intervention by the control element and the recognition of the result, he must derive only the control element activity from the task. Then one speaks of an open loop *control*. The process can be influenced by environmental factors. In this case more exactly is to be fixed, whether this influence refers on the human operator and his abilities (e.g., noise), on the transfer between human actor and machine (e.g. mechanical vibration) and on the machine itself (e.g. disturbance of the function by electromagnetic fields).

In the case of *parallel connection* of human operator and machine an observer's activity comes up to the operator (so-called *monitive system*). The machine, designed as an automatic machine, changes independently the information describing the task in the desired result. If the person observes inadmissible divergences or other irregularities, he intervenes in the process and interrupts the process or takes over the regulation from hand. Also this process can be influenced by the environment, whereby again the operator, the machine and the transference ways are the typical influencing points.

The system development is to be divided into temporal *phases* and duties typical for phase are to be done. Basis for it is the *life cycle of* a system. As Döring (1982) has worked out, the role of the human operator is to be considered in the *concept and definition phase* in an order analysis and function analysis and the functional subdivision arising from it between person and machine. Then in the *development* and *production phase* the exact design of the interface between operator and machine occurs, while in the *installation and operating phase* the final assessment takes place. For the *decommissioning phase* the same cycle is to be considered like for the commissioning phase. Its meaning recently becomes evident, actually, when one only recognizes, that the removal of the so-called industrial garbage cannot leave any more only to scrap metal traders.

4.1.1 Application of the "Cause Effect Principle"

If one describes the function of elements within a system by functions in principle on the base of a given input function an unambiguously output function or result function can be predicted. This thought corresponds to the usual *cause effect principle*. The basic advantage of this method on which practically the success of the whole technical development is based lies substantially in the fact that relatively long-term predictions are possible and that in complicated systems the temporal-logical structure of the interaction of the single elements can be fixed precisely.

Aim of the closed loop control circuit is to follow time depending forcing function and/or to compensate time depending changing disturbance variables. With it the dynamic qualities of the single system elements and the whole control circuit play a dominant role. In order to describe these dynamic qualities or to test, two procedures more differently complementary to each other are used, by which two extremes of the behavior of the system elements or the whole control circuit are described: by the so-called *step response* the reaction to a suddenly appearing change (e.g. in the case of car driving: Interception of the car with a suddenly appearing wind gust) and by the *frequency response* the behavior in the so-called steady state (e.g. in the case of car driving: To continue along a bendy country road) is described. With both procedures the basic idea of the quality is used to the mathematical description: whether related to the whole control circuit or related to a single system element, always the relation of the output signal to input signal is formed. In the case of the step response these dimensions are looked as a function of the time and in the case of the frequency response as a function of the frequency.

In most cases it is difficult – if not impossibly – to describe the behavior of the human operator for the purposes of mathematical functions. Nevertheless this happens in special cases, e.g., in the form of the so-called “paper pilot”: In this case the frequency response of the human operator is formulated mathematically. This modeling permits to a certain extent the advance calculation of the effect of different technical qualities of the machine – especially of an aircraft – on the system behavior in connection with the controlling person (see also see also McRuer and Krendel 1974). However, this modeling can have validity in this form only for *highly skilled activities*. In the situations which demand rather cognitive abilities of the person, the modeling which describes his *decision behavior* is necessary.

4.1.2 Probabilistic Methods

Now, however, the experience shows that human and technical system elements do not function under all circumstances for the thought purposes. With respect to the above referred image, that also the whole system shows an order deviating from the “natural” circumstances – that means that it represents information – is to be expected that its structure disintegrates by itself according to the second law of the thermodynamics, and so his function loses. This is the cause for the failure of elements and systems, however, also on the side of the human organism of the forming of illnesses and inadequacy. In the case of human operator as an adaptive system additionally can be assumed that he is possibly almost enforced by an “internal deviation generator” to make occasionally mistakes in order to develop new experience from it. Of course in the technical area the decay speed is very different as a function of specific material conditions (see, e.g.: Information of a writing in stone chiseled or in sand written); the decay speed can be influenced by choice of the material, the thickness of the material or the cleanness of the material to a great extent (nevertheless, the object of the traditional security technology), however, the decay cannot become completely prevented. The inherent randomness of the decay marks also the meaning of bringing in human action for servicing and maintenance tasks: while in clear cases it still succeeds to automate the (regular) normal process because here – indeed, only in less complicated cases – the possible influence to taking conditions can be thought ahead, this is practically impossible in case of the servicing and especially maintenance tasks. The application of the human operator is necessary here who can react by means of his creative intelligence to the different, in principle no predictable cases.

In order to define the probability of the appearance in the case of the countable error is to be fixed under which conditions one speaks of an error. The definition 1 of the quality can be taken again for it. The quality defined as analogous (i.e. continuous) value is usually digitized in the practical use, while quality classes are formed. The easiest form shows the classification “quality o.k.” – “quality not o.k.”. Then an accomplishing of the task beyond demanded quality borders, i.e. beyond the *“acceptance area”* will be called *“error”*. This error concept stands according to the error concept of DIN V 19 250 (1989) which understands under this the deviation going out a defined range of tolerance of a unit. If this error is caused by a human action, this is called Human Error.

One counts now the errors afterwards (*a posteriori*) and forms their relative frequency or determinates from the start *(a priori*) on the basis of mathematical calculations and assumptions of the probability distribution the likelihood for the appearance of an error. By this one receives the numerical values with which one can calculate the error probability of single elements and also of the human operator. So, by use of the Boolean algebra the total error probability can be calculated including the human influence.

The way of thinking in probability (so-called probabilistic procedure) shown only sketchy here may not be understood as an alternative to the classical cause effect way of thinking. The function of a system can be achieved only with this and formed by means of scientific methods. However, in addition, the probability oriented approach delivers other possibilities to gain control of the reliability and security of an increasingly more complicated becoming technology and in particular also the mashing of this with the environment and the controlling person.

4.2 Information Technological Human Model

4.2.1 Human Information Processing

In order to describe the interaction between human operator and machine with the aim of the design according to an engineering approach, the technical information modeling of the human operator is necessary. The system element man is represented graphically like every system element as a rectangle with an input (ordinarily on the left side) and an output (ordinarily on the right side). The input side of the person, the *information perception* is defined by his senses, like eyes, ears, etc. The information taken up is changed in transformed form on the output, the *motor processing* into one of the outside world sensible information. This is characterized by the possibility to bring the extremities hands and legs in desired positions (and motion), but also by the speech. The central nervous system which connects together the from the outside coming information with each other, carries out logical derivations, and makes decisions, is called *information processing*.

However, with this characterizing is to be considered that a sharp separation is possible between these human subsystems neither from physiological nor from psychological view. In the information processing in the narrower sense the taken up information is connected together with commemorative contents by logical deriving, drawing of conclusions and by decisions. Rasmussen (1987) describes three level of information processing:

1. Often repeated connections which turn out useful are learned as combined actions (so-called internal models) which can be realized unconsciously, virtually automatically, i.e. with low (or to none) deliberate expenditure (*skill-based*

behavior). These actions are quick: The time difference between the stimulus and the reaction lies between 100 and 200 ms (e.g., driving a car on a winding street).

2. Furthermore taken up signals can be processed by reminding and the use of stored rules, after the pattern: "if… a symptom…, then… an action" (*rule-based behavior*). This action manner requires a certain deliberate expenditure (e.g.: Follow the "right has priority for left" rule in the traffic). The searching and the choice of these rules require the expenditure of seconds or even minutes depending on the different situations.
3. Planning, decision and problem solving in new situations are mental achievements at the highest level of the information processing and correspond to the so-called *knowledge-based behavior* (e.g., diagnosis of the failure causes of a complicated system). According to kind of the task and the measure of the closeness linked with it the treatment of parallel tasks is not possible. These actions require as a function of the difficulty of the task a time demand of minutes to even hours.

In general the probability of a false action rises if the treatment time necessary at the respective treatment level ("required time") is given equal or is even greater than objective the time span within which the task is to be done ("available time"). For a significant degradation of the error probability the available time must be bigger possibly around the factor 2 than the required time. In order to guarantee quick perception of technically displayed information the aspects of information retrieval as shortly shown in Fig. 7 are of outstanding importance.

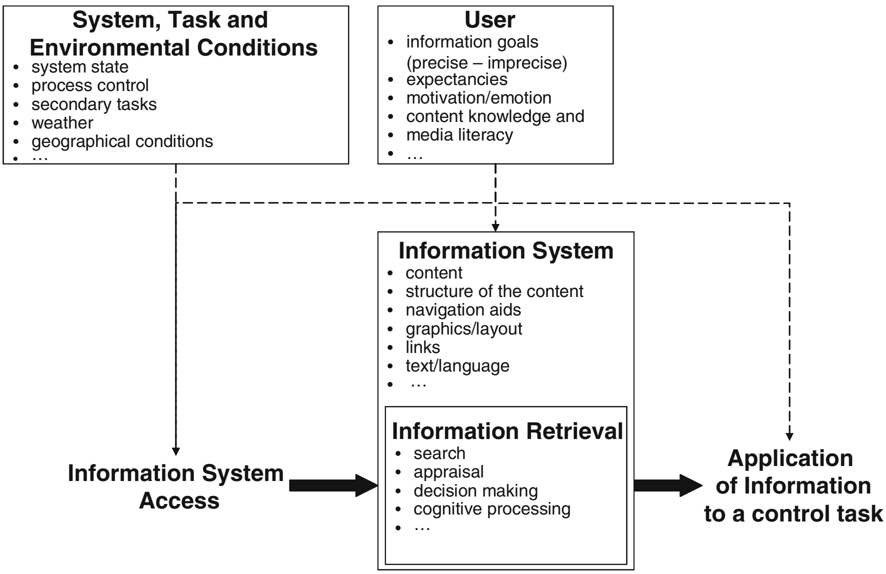


Fig. 7 Control circuit of the human machine system with the nomenclature usual in the control engineering

For the design of machines are the works of Pöppel (2000) of great importance. He found out that the area of the immediately experienced presence is given by about 2–3 s. In particular many investigations from the traffic research support the image of this limit which is given by this 2–3 s horizon (e.g., Gengenbach 1997; Crossmann and Szostak 1969; Zwahlen 1988). However, Pöppel also points to the fact, that additional to this immediate present feeling still the area of the so-called "present of the past", i.e. the recollection of the immediately before events and the so-called "present of the future" belongs. The last refers to the expectation of that what happens at the next moment. The whole span of present of the past up to present of the future puts out about 10–15 s and encloses the time span, in which the so-called working memory immediately can be processed.

Although every human *motor processing* can be led back basically on muscle movement, must be distinguished in practice between the change of information by:

- Finger, hand, foot activity and
- Linguistic input.

The technical equipment can be adapted to the conditions of the motor processing by suitable design:

- Adaptation of the control elements to the anatomical qualities of the person;
- Sufficient haptical distinguishability of the control elements;
- Enough force feedback by the control element;
- Feedback of the influenced process.

The transference of information by language plays a big role above all with the intercommunication between people. In general communication problems are on the one hand effects of the perception of information (e.g., masking of the language by noises) and on the other hand of semantic kind. To the latter problem is thereby tried to prevent often that one uses standardized expressions within a certain technical system (e.g.: air traffic). However, the linguistic input also plays in the human machine communication increasingly a role. The performance and reliability of the conversion of information by language (linguistic input) is influenced by factors which are due to the speaker, to the used word repertoire and text repertoire, from the qualities of the speech recognition system and to surroundings noises (see Mutschler 1982). In this area are reached at the moment of big progress (Wahlster 2002).

However, in general no human activities exist that are total errorless. In many cases the human operator recognizes often immediately that he failed. In this connection information retrieval plays additionally an important role. By technical means is to be provided that every step that was initiated by the human operator can be retrieved at any time. Often that can be realized by an "undo function" that recalls the last step. In more complicated cases additionally a back step to the start position or a meaningful interim state is necessary.

4.2.2 Modeling of Human Decision Behavior

For the development of technical aid it is basic among other things to identify the dimensions of influence for decisions. The modeling of human decisions serves it. One receives a clear representation in form the so-called decision matrix (Schneeweiß 1967). In this the respective circumstances under which an action occurs are laid down for example in the columns and in the lines the possible actions. The likelihood of the appearance of these situations is estimated on the base of the experience (internal model). Then a (thought) event can be assigned to every combination of situation and action to which in each case an individual benefit or damage (= negative benefit) corresponds. Then the action is selected, which promises most benefit in the sum or allows expecting the slightest damage.

With regard to the technical human models based on control theory as well as the modeling of the human decision is to be bent forwards a wrong claim appearing over and over again. The aim of such ergonomic human models does not consist in "to explaining" the human being. It is not a matter of uncovering the effect mechanisms on biological, physiological or also psychological base precisely for the purposes of a "establishing of the truth" and of reaching with it a progress in the science of the knowledge about the human existence. This stands, for the rest, in perfect analogy to the anthropometric human models which also want to fulfill no medical–physiological claims. The objective is in both cases of rather purely pragmatic nature: it is, to simplify the won knowledge about the human behavior in the different appealed science disciplines and to concentrate it in a model in such a manner that can be derived from its – very unequivocal – conclusions for the technical design. Jürgensohn (2000) found out, for example that control theory based human model can represent always only one limit area of human behavior. Therefore, in particular the rather technically oriented models should be connected in future with models from the psychological area. But also cognition ergonomic human models want to predict the realization of certain decisions neither nor explain, but from a rather general view derive in similar manner tips to technical improvements as it is possible for the dynamic interaction on the fundament of control theory based models.

5 Aspects of Information Ergonomic Design

On the basis of the preceding exposition the cognition ergonomic design area can be founded. Every working task requires a cognitive processing expenditure from the person. Depending on the design of the working means this processing expenditure can be reduced and with it the mental load, but be raised also. The optimization of the mental load, i.e. neither under demand nor excessive demand of the cognitive processing possibilities, is the object of the cognitive ergonomics.

As quite in general for the whole use of ergonomic knowledge the following two approaches are also to be distinguished with regard to cognitive questions:

– The *retrospective measurement* of the goodness of an existing design solution concerning cognitive load, to be equated with the so-called corrective ergonomics and
– The *proactive design* of a system with the aim to minimize the cognitive load which corresponds to the so-called prospective ergonomics.

Presently in the area of the cognitive ergonomics still the retrospective approach controls the design process. After a system has been designed and created cognitive charges are measured (e.g., by questionnaires, user tests, simulations). This as *prototyping* known approach permits to clear cognition psychological questions only with existence of a system or at least a prototype (Balzert 1988). A reason for the dominance of the retrospective approach is the fact that cognitive loads are hardly predictable in a not closer specified technical system. However, on the other side those *post factum* investigations are always cost-intensive and are time consuming when the design solution must be reworked, because repeated going through of the design cycles forces them. Accordingly seldom technical systems are reshaped, even if it could be shown that they have led to events or accidents (Sträter and Van Damme 2004).

For this reason proactive creation methods were developed increasingly to the more efficient design concerning development time and development expenses (Hollnagel 2003). They are based on cybernetic, system-ergonomic approach which investigate the flow of information between person and machine concerning the in principle possible effort of code conversion (and with it of the cognitive load in principle to be expected).

Effort of code conversion can be distinguished in principle at two interaction levels (Balzert 1988):

– The relationship of the mental model of the user and the actual working principle of a technical system at the *representation level* or
– The relationship of the user desired and from the technical system demanded operating processes at the *dialogue level*.

This can be illustrated in the problem triangle shown in Fig. 8 which is put up between the poles system designer, actual realization and user to themselves. The system designer converts his internal imagination of the system and his possible use in a construction. The realization of it, which is not produced generally by the designer itself, cannot agree under circumstances by inserting other actors with the planned construction completely. The internal representation of the user of the arrangement can deviate from the realization as well as from the image of the designer. In the described discrepancies an essential source lies for misinterpretations and erroneousness operation.

Different cognitive control modes arise from this general connection that describes specific cognitive demands for the human operator (Hollnagel 1998). According to the stress and strain concept these cognitive demands lead to cognitive

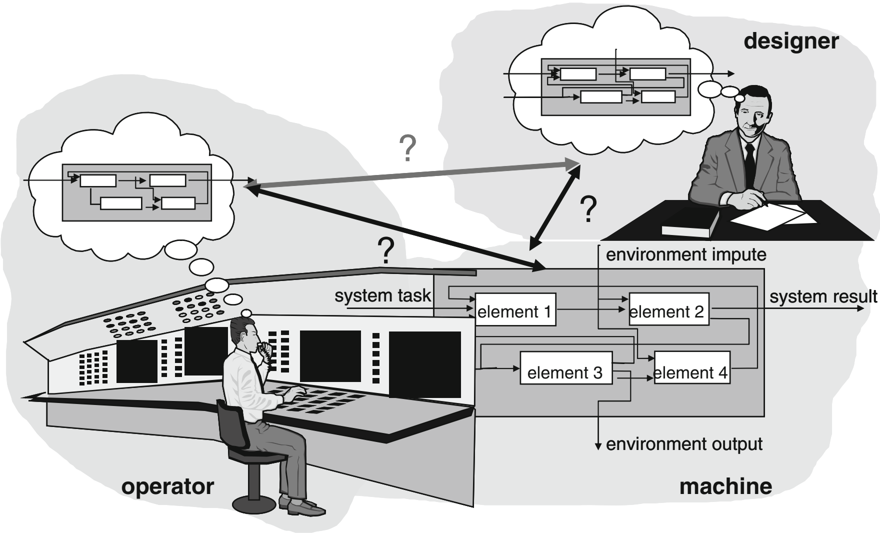


Fig. 8 Problem triangle between designer, realization of the system, and users

load. In a broadly invested research project to communication behavior in groups could be shown that these control modes and the cognitive loads following from them are also valid analogously for the human person's communication (GIHRE 2004; GIHRE stands for "Group interaction in High Risk Environments").

By the consideration of ergonomic design rules it is possible to give concrete advices how these demands can be fulfilled. These design rules are derived from system-ergonomic results of the research. They can be applied quite in general for the human operation design of machines.

For the ergonomic design of the task which arise from the system order and from the especially elective design of the system and the system components (e.g., of the software), the following basic rules which are formulated here as questions must be considered:

(a) *Function*: "What intends the operator and to what extent does the technical system support him?"
(b) *Feedback*: "Can the operator recognize whether has he caused something and what was the result of his action?"
(c) *Compatibility*: "How big is of the effort of code conversation for the operator between different canals of information?"

Figure 9 gives an overview, how the system-ergonomic design maxim "function", "feedback" and "compatibility" are further subdivided. Therefore, the function can be disassembled in the real task contents and the task design. How both names already imply, the contents arise from the logic basic of the task, while the task design is carried out by the system designer.

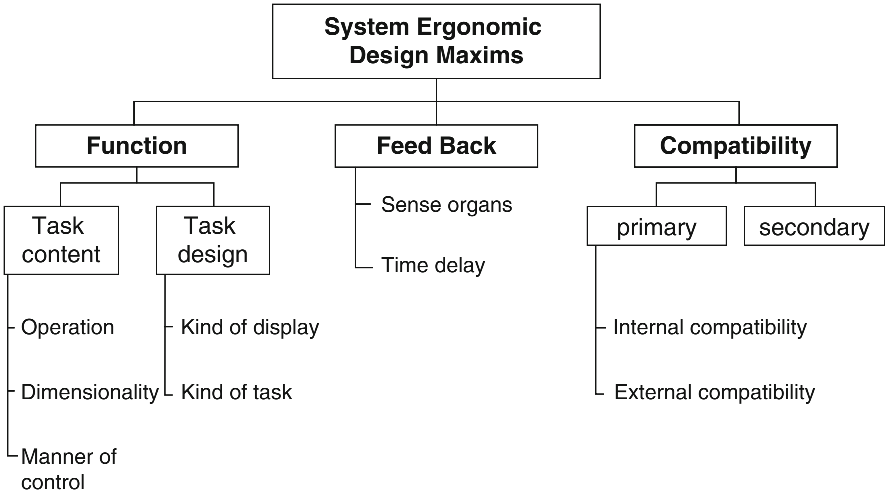


Fig. 9 Overview of the system-ergonomic design maxim function, feedback and compatibility

5.1 Function

The *function* refers on the one hand to the real *task content* that is fixed and describes substantially the change of information demanded by the human operator, and, on the other hand, on the *task design* that can be influenced within the scope of the respective technical possibilities by the system designer. The mental load of the operator is influenced by the complexity of the task, as well as by such aspects of the task which are determined by the provided technical system. Therefore the task of the system designer is to reduce the design-conditioned operating difficulty as much as possible by a favorable design, so that finally only the immanent of the task difficulty is left.

5.1.1 Task Content

Operation: Every task can be described by its temporal and spatial order of the necessary activities. For example, during the approach for a landing the aerodynamic lift decreased by the increasingly diminished speed must be compensated by moving out different landing airbrakes. Therefore, it is the task of the pilot to operate these landing airbrakes in a temporal sequence depending on the ongoing speed. Simultaneously he has to compensate different spatial air streams by separately operating the landing airbrakes of the right and left side of the airplane.

Thereby *temporal aspects* can be categorized by the differentiation in *simultaneous* and *sequential* operation. If the order of the necessary working steps is time wise given, one speaks of a sequential operation. It calls the fact that from objective point of view (not caused by the realized software!) certain processes in this and only this order are to be treaded (in the present example: Reaming of an undercut). If there is no essentially given temporal order of the working steps, a simultaneous process is given. “Simultaneous” means here an arrangement of equal standing of different choice possibilities, on this occasion, i.e. that different tasks stand in a queue at the same time and it is put in the pleasure of the operator in which order he accomplishes the tasks.

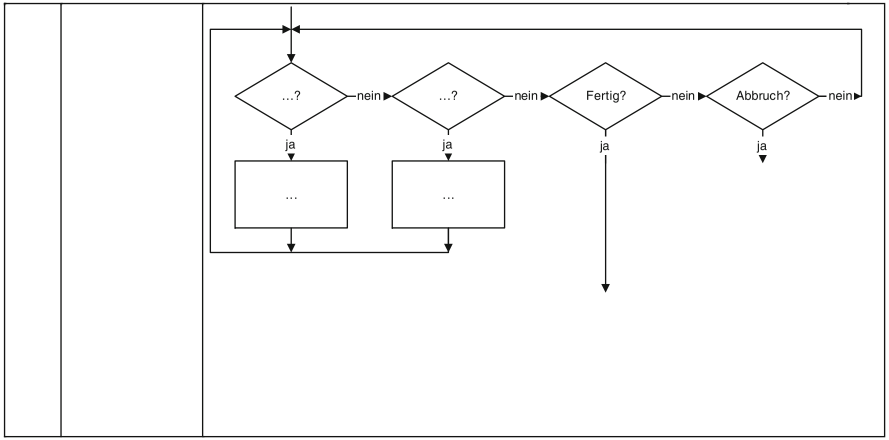
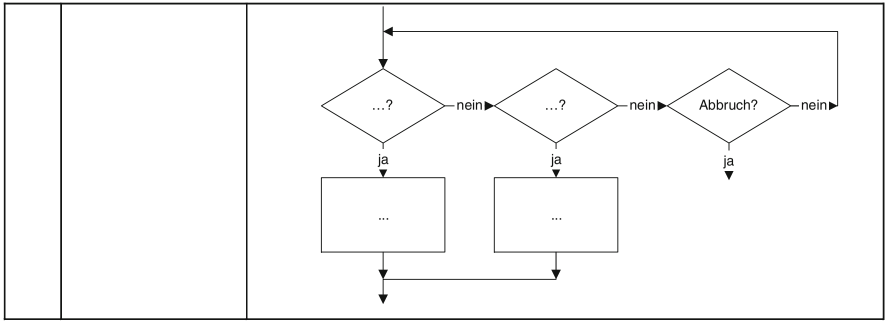
As soon as the user has the choice of several possibilities, a simultaneous operation is demanded by him. Altogether three different types, namely simultaneous operation of *compelling*, *varying* and *divergent kind* can be divided outgoing by these decisive possibilities (Rassl 2004). With the compelling kind several working steps stand in a queue at the same time for the decision. Each must be carried out to the fulfillment of the task. A typical pattern for a simultaneous operation of compelling kind is complete filling up a personal record. In this case the task consists in giving all data. Whether, nevertheless, first the given name or surname is put down on the record, is irrelevant for the result. Also with the varying kind different working steps stand in a queue at the same time for the decision. However, not each must be worked on because every possible step leads to the aim. To the fulfillment of the task it is enough to explain only one working step. An example is the choice of different route proposals in a navigation system (highway, yes/no, toll streets avoid, the quickest/ shortest distance etc.) which lead, however, in every case to the same destination. A simultaneous operation of divergent kind is given if the choice leads to different results. An example of it is the choice of destinations from the addressing memory of a navigation system. In Table 1 the three types of the simultaneous operation with a schematic flowchart in each case are summarized.

The temporal order of tasks is shown suitable-wise with a flowchart. In this flowchart by rhomb needs of information on the part of the machine (the machine cannot know what the operator wants) are characterized and by rectangles actions of the operator by which he transfers information on the machine. In the first step of an information ergonomic solution a so-called demand flowchart is to be created, which shows the necessary temporal order of the information transfer to the machine from the point of the operator without consideration of any technical realisation possibilities. Then from it is already to be derived, which tasks are simultaneous and which are sequential. In the case of simultaneous tasks it must be left to the operator which operating step he chooses first. The order of an essentially necessary sequence should be given on the other hand firmly in the software programme or by the arrangement of the control elements and the operator must have in suitable manner feedback about that on with which step the system just is.

The analysis of the operation is basic for every information ergonomic design. Now in the next analysis steps the respective ergonomic design must be carried out for each of the single actions which are characterized in the flowchart by rectangles.

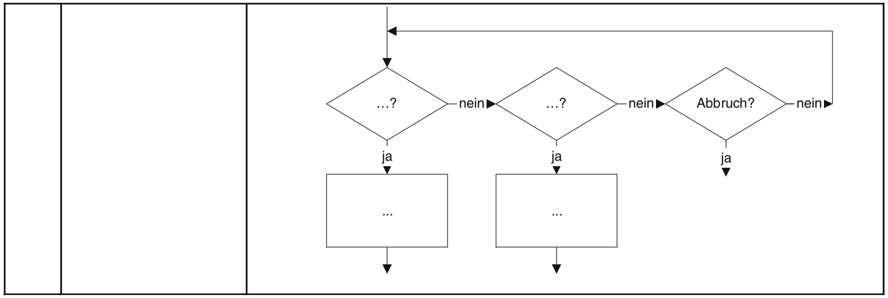
Dimensionality: The difficulty of the *spatial order of* the task depends on the number of the dimensions on which the operator must have influence. A task is easy if only *one dimension* (e.g., the setting of a pointer on an analogous instrument) or *two dimensions* (e.g., the setting of a point on the screen of a computer must be

Table 1 Summary of three subspecies of the simultaneous operation. According to prevailing simultaneous choice possibilities this presents itself differently

Compelling kind	Several working steps stand in a queue for the simultaneous decision Every working step must be carried out Order of the processing is irrelevant for the result	
Varying kind	Several working steps stand in a queue for the simultaneous decision Only one working step must be carried out to the task fulfillment Every working step leads to the aim	

(continued)

Table 1 (continued)

Divergent kind	Several working steps stand in a queue for the simultaneous decision Not every working step must be carried out The single working steps lead to different results	

controlled by means of the mouse or the steering an automobile on two dimensional surface of the world) are to be controlled; in itself is a three-dimensional task also easy (e.g., piloting an airplane – the difficulty lies here in the control of the dynamic of the airplane), however, can become quite difficult by the necessary representation on a two-dimensional screen. In any case it is more difficult if it becomes necessary to control *four dimensions* (e.g. controlling a portal crane, as it is necessary to influence as the longitudinal as the transversal, the height movement as well as the orientation of the load around vertical axis) and especially difficultly if *six dimensions* must be influenced (e.g., positioning of a component for the purpose of the assembly or docking maneuver of a spaceship in the orbit).

Ergonomic improvements are reached if the number of the control elements is nearly immediately with the number of the influenced dimensions (e.g., the two-dimensional task of the motoring can become safer and more efficient if the control elements of a hand-switched car are substituted by an automatic, with only three control elements; the movement of a pointer on the two-dimensional screen surface by the two-dimensional movable mouse shows on the other hand almost an operating-ergonomic optimum. The control of an object in a quasi-three-dimensional representation on the screen by an operating element shows on the other hand an ergonomic challenge; the so-called space-mouse is an example of a good beginning in this direction).

Manner of control: In some cases the task is to be accomplished within a certain time window, what possibly time pressure originates, or within a certain local window (local window: the limited surface of the screen often makes a movement of the whole contents necessary. This leads to quite specific compatibility problems; see the following segment 5.1.2 and 5.3). A big time window characterises *static tasks* and a small time window *dynamic tasks*. Static tasks are characterised by instructions (nearly) independent of time with regard to the demanded end product (e.g., reading a value of a display; work on a lathe: only the final qualities of the work piece to be worked on are described by the drawing, not, nevertheless, the way, how this is produced). With time budget the relation required at the available time is called. It should not cross values more than 0.5. Then it is well possible to correct an observed mistake. Under this aspect it is to be rejected, by the way, ergonomically that certain operating setting are automatically put back after a certain time. In any case, better is a reset button deliberately to be operated by the operator. Dynamic tasks are characterized by the continuous service of a machine (e.g., driving a car on a winding street; directly operating a tool machine of the calculator console from).

5.1.2 Task Design

Kind of display: The difficulty of the task can be influenced furthermore by the way of the indication of task and result. In case of a technical indication the task and the result either can be indicated separately, or only its difference.

In the case of the separate indication one speaks of a *pursuit task*; it is recommended in observation situations which are earth-firmly installed, outside of vehicles (e.g., airplanes on the radar screen of the air traffic control or position of a marker in a CAD drawing). In this case the operator can win information about the movement or the change of the task and the result independently of each other. Therefore, he can make short-term predictions about the future movement of both and react consequently on time. Moreover, he thereby receives – with correct design of the compatibility (see Sect. 5.3) – a correct image of the reality on the display what makes easier the orientation to him.

In case of the indication of the difference of task and result one speaks of a *compensation task*. In technical systems this is often preferred because the display amplification can be freely chosen. Depending on the situation however, one exchanges this advantage by fundamental compatibility problems.

In connection with the operating surfaces of software one deals generally with the display of the pursuit task (by means of the mouse one can move to the single positions on the screen whereby their position does not depend on the mouse position). Because the screen window is limited by the size of the monitor, however, a movement of the representation is often necessary. Then one uses scrollbar. In this connection, there appears a compatibility problem which is very similar to the compatibility problem described below in vehicles: Is the position of the section or the position of the object behind the section moved by the scrollbar? The problem is solvable by the change to the pursuit task: while the cursor is brought on a free field (background) of the representation, the screen contents can be shifted with the pressed mouse key compatibly with direction.

The guidance of a car by the view on the natural surrounding is always a compensation task, because only the difference can be perceived between the own position and the desired position in the outside world. Therefore, the dimensions which deal with the outside world (e.g. representation of the correct course at a crossroad in a car by a navigation system; information of the run way in the case of the landing flight and the artificial horizon in the airplane) have to be shown in the form of a compensatory display from the view of information ergonomics. However, there arises in principle a compatibility problem (see Sect. 5.3), because with the steering movement the own vehicle is moved in relation to the fixed environment. This is presented to the driver of a vehicle, however, in such a way, as if the environment is moved in relation to the fixed vehicle. This discrepancy with the look at the natural environment ordinarily plays no role because the movement of own vehicle is natural for the driver of a vehicle. The example of the artificial horizon in the airplane and the difficulties, the pilots with it in the case of pure instrument flight have, however, shows the problem (see more in Fig. 10). The dilemma can be compensated by help of the contact-analogous indication in the HUD, because in this case the indication provides for the pilot of a vehicle the same information like the natural environment.

Kind of task: For the person operating the machine it is a basic difference whether he himself is integrated actively into the working process, or whether he has to fix only the basic settings of an automated process and then to observe the successful running. One speaks of *active* or *monitive* task of the person. Because

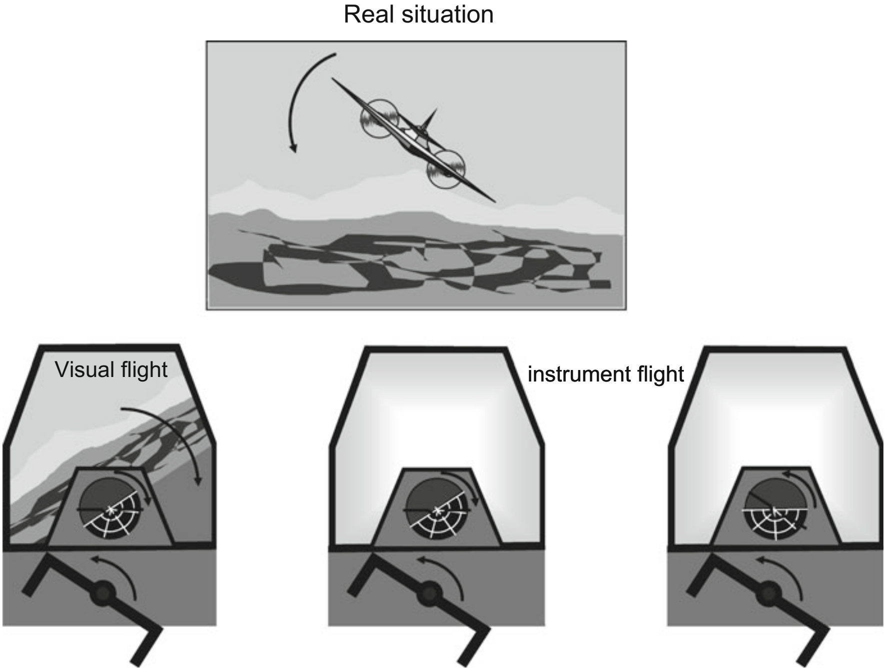


Fig. 10 Possible forms of presentation of the artificial horizon in the airplane. In the case of the instrument flight it comes to an incompatibility between the necessary movement of the steering gear and the reaction of the movable part of the artificial horizon (instrument flight on the *left*). If a movable airplane symbol is shown (instrument flight on the *right*), the movement direction of steering gear and the indication is compatible though, the movement of the airplane symbol, however, is incompatible to the movement of the outside view, in the case free sight conditions exist

these are almost the domain of the computer to regulate also a complicated process intelligently, today such automated processes win more and more in meaning.

Well known qualities of the person and those of the machine can be pulled up for the decision of the choice between automatic and manual control: Automation must be recommended in general if problems with human borders appear concerning the exactness, quickness and reliability. Nevertheless, this is correct only if exclusively such situations occur, for which the designer has made arrangements. Because for this, nevertheless, no guarantee can be given, a certain integration of the person is necessary in every system.

Monitive systems have disadvantages which arise from the risk of the monotony and lead therefore to a loss of the watchfulness of the operator. Moreover, the operator is by the constantly working automatic of the system relatively unskilled with the contact of the system elements and their impacts. In particular arises the disadvantage that the operator gets difficulties with the system control on account of his insufficient familiarity with the system in the case of a possible failure of the automatic. It arise the problem of the so-called situation awareness. In some cases because of the complexity of the situation and the impossibility to take up technical signals and to process (e.g. in the public traffic) an automation is not at all completely possibly.

With the systems in which automation is realizable (e.g., in most power stations and process observations) is to be respected in view of the overall reliability of the system to integrate actively the operator anyhow into the system because thus his attention and his training state remain maintained. The advantages of a monitive system for a reliable system in preplanned situations could be preserved in connection with this demand if only the local and temporal borders are determined by a machine within which the operator has to hold the dimensions to be influenced of the system. Then the operator has to drive within these borders the system always himself. If he touches the borders, this is given for him by the system in adequate manner (see "feedback") and he can decide whether he follows the recommendation of the automatic or takes over the regulation himself (today this "philosophy" becomes more and more applied for the concept of so-called advanced driver's assistance systems – ADAS – in the automobile).

5.2 Feed Back

The feedback of the achieved state to the operator is one of the most important factors by which a coherent understanding of the system state can be provided. If the information about the state of the system can be provided by different senses organs, this redundancy is to be evaluated in general positively. The human situation capture ("situation awareness") rises if the same information is perceived by more than two senses organs (indication of a danger by lighting up of a control lamp *and* an acoustic signal). Another especially important aspect is the time span which exists between the input information in control element and the reaction of the system on the output side. If this time exceeds more than 100–200 ms (response time of the information perception) this leads to the confusion and disorientation of the operator. If such a time delay is not avoidable for technical reasons, this must be indicated to the operator (e.g., in the most primitive manner by the known "hourglass symbol"). If the time delay amounts more than 2 s., so the process to be regulated appears to the operator like a open control system. Then he needs at least the immediate feedback about the operated system input (e.g., high lighten of the button). However, the exact feedback about the progress of the process is better in this case (e.g., Indication by a growing beam and information of the rest time to be expected after initiation of a computer program).

If the points demonstrated here are followed, a well formed feedback always permits the answer to the questions to the operator:

– "What have I done?"
– "In which state is the system?"

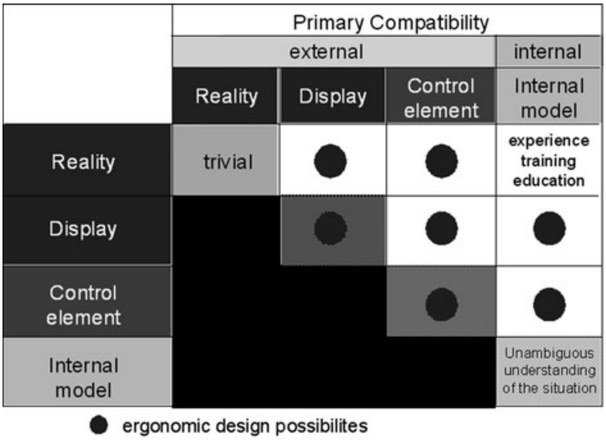


Fig. 11 Ergonomic design areas of the compatibility

5.3 Compatibility

Compatibility describes the easiness with which an operator is able to change the code system between different canals of information. Hereby is to be distinguished between primary and secondary compatibility.

Primary compatibility refers to the possible combinations of different areas of information like reality, displays, control elements and internal models of the operator (see Figure 11). Within the primary compatibility can be distinguished furthermore between external and internal compatibility: External compatibility refers to the interaction between person and machine concerning the outside world ("reality"; an example for this is the already discussed compatibility of steering gear and artificial horizon in the airplane; see Figure 10), while internal compatibility considers the interaction between the outside world and the suitable internal models of the person. As shown in Figure 11, an ergonomic design is possible only in certain areas. Thus, e.g., the compatibility of different information from the reality is trivial. On the other hand, compatibility can be reached between the reality and internal models only by experience, training and education. Compatibility between different internal models corresponds to an understanding free of contradiction of the situation. Every person has certain inconsistencies concerning the representations in different areas of his memory. The remaining areas in Figure 11 can be designed ergonomically in the sense that, for example, a movement forwards or to the right in the reality corresponds to a movement forward or to the right in the pointer or in the control element etc. This so-called spatial compatibility plays a prominent role in connection with the representation of the real outside world on a display (e.g., screen).

The internal compatibility is characterized by so-called stereotypes (see Fig. 12) that possibly only in the western society have this meaning (probably caused by the writing habit from the left to the right and from above down).

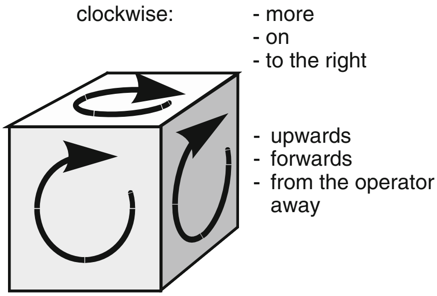


Fig. 12 Stereotypes

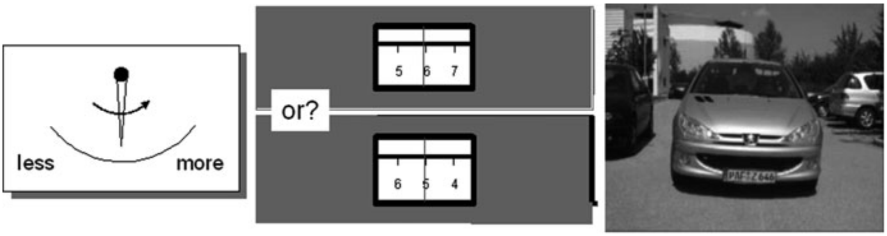


Fig. 13 Examples of secondary compatibility

Secondary compatibility means that an internal contradiction is avoided between partial aspects of the compatibility. Thus, for example, a hanging pointer is secondarily incompatible as there the movement from "on the left = a low" to "on the right = a much" (this in itself is compatible) is connected incompatibly with an anti-clockwise turn of the pointer. Also the case of "standing pointer – moved scale" is secondarily incompatible because here the movement direction of the scale is always incompatible to the arrangement of the order of rank of the digits. Another example is the arrangement of the indicator in the internal corner of the headlight of a car. In this case the position of the flashing light in the headlight case is incompatible to the position of the headlight in the vehicle. Figure 13 shows examples. Secondary incompatibility seems to be unimportant in the first sight because one understands in case of a rational consideration "nevertheless, easily how it is thought". However, in a critical situation, where it is important that information is perceived fast and reliably, just the secondary incompatibility can be occasion for a misinterpretation.

6 Conclusion

In the past especially ergonomics oriented in the physiology was more in the foreground by which unfavourable physical load could be recorded and reduced. In the next phase of the development the anthropometric ergonomics won importance by which the width of different body dimensions found consideration. Therefore unfavourable postures could be avoided; sight spheres and grasping spheres adapted to different sized individuals could be designed. Further on seat comfort could be improved. Excited by the rapid progress of the calculator technology today the information ergonomics comes in the focus of the consideration. It is a challenge of first rank to design the interaction of the intelligent person with intelligent machines. The progress of psychological research brings it with itself that the human information processing is understood better and better and by this can be modelled itself. Therefore, to a certain extent it is possible to precalculate the human behaviour in certain situations and to base on it the design of the interaction man and machine. Within the scope of the system ergonomics one has started very early developing rules for the creation of this interaction. These have of course also validity in connection with systems, which are controlled in excessive manner by the computer. Nevertheless, a change of gravity arises by the new possibilities above all also sped up by the sophisticated computer technology to visualise information. Thus information ergonomics wins importance as it is especially concerned with this topic. Some basic rules were shown in the present chapter which form the fundament for a information oriented design of the interaction man and machine.

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