

# Ergonomics and human reliability

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**Abstract:** Research results in the area of ‘human reliability’ enable calculations to be made of the probability of human error, but also an acknowledgement of the ability of the human operator to recognize an unwanted process and to avoid it. Connectionism assessment of human reliability (CAHR) is a newly developed system that evaluates events, thereby making it possible to find conditions of cognitive error and develop strategies to reduce the probability of human error. It can be shown that aside from organizational measures, ergonomic improvements are of especially profound importance in the aim to optimize error management.

**Keywords:** ergonomics, human reliability, connectionism assessment, human error

## 1 INTRODUCTION

It is a well-known fact that the influence of human action on the reliability and availability of technical systems and machines is of significant importance. It is often argued that between 70 and 80 per cent of all malfunctions may be related to so-called ‘human error’. In a certain manner, this is a trivial observation, as for most problem-related actions in technical surroundings, human influence is necessary for the actual event to be initiated. Even in the context of a completely automatic controlled process, either the programme procedure is determined by human activity or the unacceptable procedure is at least avoided in the last moment by human intervention. There are very few processes for which the final action is not accounted for by the action of an individual involved in some way in the process itself. This is also reflected in legal practice.

The term ‘human reliability’ is often used without a clear understanding of what is actually meant. Two separate ideas are understood which often lead to misunderstanding:

1. In the colloquial usage, ‘human reliability’ is regarded basically as a positive attitude, indicating an individual’s inclination to take *responsibility* for adopting a way of acting that is helpful rather than harmful to others.
2. In the more technically oriented ergonomic understanding of ‘human reliability’, the *probability of*

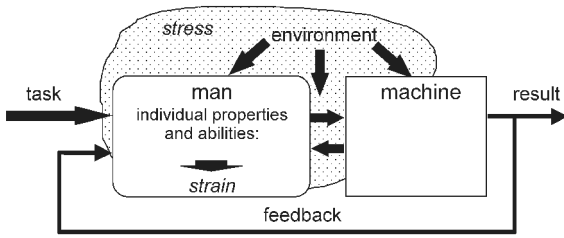
*functionality* of a technical system is considered, which is not influenced by occasional human errors or caused by insufficient layout of the man–machine interface.

## 2 DISCUSSION

As a focal point for the consideration of human behaviour in connection with machines, the closed-loop paradigm can be taken into consideration (see Fig. 1). This is also the fundamental diagram of ergonomics [1]. At the input side of the system is the task, which has to be completed by the system (task setting). The output of the overall system is the result (accomplishment of task) and the interaction of man and machine can be modified by the environment. External influence on the human being is called workload. Depending on individual characteristics and capabilities, this workload translates into stress for the respective human being. The result of the work process is measured relative to the task. The degree of the task accomplishment is the quality of work. The quality of work attained in a defined period of time equals work performance. Both of the above-mentioned factors influencing the interaction of man and machine, i.e. the load through external influence and the individual performance prerequisites, are defined as the so-called ‘performance shaping factors’ (PSF). The combination of the external workload and the performance prerequisites results in individual strain.

With regard to quality, the limits of tolerance are to be defined. When these limits are exceeded, then an ‘error’ has occurred. In the case that the error is initiated by a human action, we call it ‘human error’. The following

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$$\text{quality} = \frac{\text{result}}{\text{task}} \quad \text{performance} = \frac{\text{quality}}{\text{time}}$$

**Fig. 1** Scheme of the structure of human work and related influences

hierarchical ordered limits of tolerance are considered (after reference [2]):

1. *Hard limits* are physical barriers like impacts, locking devices, safety bolts and coverings, which can be overcome only by physical and psychological effort.
2. *Technically dictated limits* are all operational regulations, which exist for physical-technical reasons in order to provide protection. Exceeding these limits is physically possible without effort, but there is always actual feedback as a result of such actions (e.g. generally the 'red area' on an instrument).
3. *Empirical limits* are also operational regulations with the same principle as the technically dictated limits. However, in this case, overstepping empirical limits cannot be observed immediately. The recognition of these limits makes necessary experience, power of recollection and the inclination for understanding the technical-operational interrelations. Part of these limits are, for example, empirical 'when-then' regulations (e.g. the exchange of a component after a fixed operation period).
4. *Conventional limits* are, among other things, legal regulations that can be derived from standards or rules. A precondition in this case is the readiness for loyalty. Normally such a problem arises when it takes more effort to obey these rules than to disregard them (a classic example is failure to wear protective clothing).

Only occasionally are the limits exceeded. Therefore human reliability is defined as a probability (human error probability, HEP):

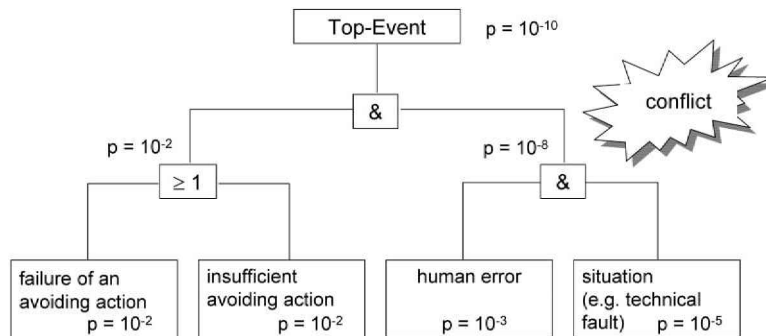
$$\text{HEP} = \frac{\text{amount of tasks of type A not sufficiently fulfilled}}{\text{amount of all tasks of type A}}$$

The probability for a certain unintended event, the so-called 'top event', can be calculated by application of Boolean algebra when the connection of the singular events that lead to the top event is known. This connection can be represented by the so-called fault tree. Figure 2 shows a typical fault tree of an unintended event caused by erroneous human operation.

This figure shows two important and general aspects of nearly every unintended event: only the coincidence of a certain (technical) situation and a corresponding human error leads to a conflict. This conflict is the precondition for the event. However, in most cases the human operator observes this conflict. The unintended event only occurs when, at this point, there is no avoiding action initiated or the avoiding action is insufficient.

### 3 THE IDEA OF SYSTEM ERGONOMICS

What is the source of human error? Besides inattention, tiredness and general human insufficiency, there is another fundamental reason for this difficulty. According to general opinion, an optimum adaptation of the operation layout of a machine to man is achieved when the individual internal model of the operation corresponds exactly with reality. In a given situation, every difference between reality and the internal model can result in an error. The designer of a machine tries to imagine this internal model of the user and to design the machine based on this image. However his image of the user's internal model is of course derived from his own perception of the operation, and this is essentially influenced by his knowledge of the technical functions. This explains, for instance, the often-repeated observation that the designer/constructor of technical equipment



**Fig. 2** General scheme of the occurrence of an unacceptable event, the so-called 'top event'

can use his machine without any problems, whereas an inexperienced user at once initiates an action that results in a latent malfunction of the apparatus. Since no scientific methods exist to examine the internal model of the user, this problem cannot actually be solved. The methods of system ergonomics serve a way to find the simplest form of operation in a given case. It can be assumed that this is very near to internal models of the operator.

The system ergonomics approach starts with a general description of the properties of every task. This is then compared with experimental experience and from there ergonomic recommendations are assigned to the partial aspects of the task. The fundamental idea is that by using the knowledge provided by this information, transfer of the subsystems of man and machine, designing the tasks to be performed by the operator can be improved. When designing a task, the system mission is taken into account, as well as the specifically chosen layout of the system and the system components (e.g. the machine). In other words, the following fundamental questions are to be considered:

1. *Function*. 'What is the operator's aim and to what extent is he assisted by the technical system?'
2. *Feedback*. 'Can the operator recognize whether he has influenced something and to what degree of success?'
3. *Compatibility*. 'How much effort does it mean for the operator to convert the coded information of signals and controls?'

These questions are answered in detail by the following assessment of the singular points.

The function may be separated into the intrinsic task contents and the task design, which can be influenced by the system planner. The task contents are essentially defined by the temporal and spacial order of the activities that are to be carried out to perform the total task. The total task may be defined by the terms 'operation' (describes the temporal order of the singular task), 'dimensionality' (describes the spacial order of the task) and 'manner of control' (the kind of temporal and spacial limit in which the task must be accomplished). In task design, the degree of difficulty may be influenced by the specifically designed layout. Task design can be distinguished by the manner of presenting the task and result to the operator, the so-called 'display', and the manner of involving the operator in the total system, the so-called 'manner of task'. The last point concerns essentially the question of automation or hand operation.

Feedback is an aspect of the system structure and also of the organization. In the case of the man-machine interface, human reliability increases if the same information is received by at least two sensory organs. A further aspect is the time from the input of information at the control element to the reaction of the system on the output side. If this time lapse increases by more

than 100–200 ms (the reaction time of the sensory processing), it leads to disturbance and disorientation of the operator. Even if the time delay is more than 2 s, the controlled process appears to the operator like an open-loop process. Considering these recommendations, well-designed feedback allows the operator to answer the questions:

1. What have I done?
2. What is the state of the system?

Incidentally, receiving sufficient answers to these questions is also of great importance in the case of organization structure.

Compatibility describes the relationships among reality, displays, controls and internal models that are consistent with human expectations. Compatibility in ergonomic design means, for example, that a movement forward or to the right corresponds in reality to a movement forward or to the right at the indicator or the control element, etc.

All these questions are treated on the basis of the closed-loop system consisting of the main elements, man and machine (see Fig. 1). By the open branches 'placing an order' and 'prompt attention to an order', the connection to further singular man-machine systems is possible. In this context, a complex working system consisting of many workers and machines can be modelled under the aspect of information flow (see Fig. 3).

As shown in the following section, the described principles of system ergonomics can be used to evaluate human reliability in skill-based situations, as well as in knowledge-based situations, which require consideration of cognitive aspects of human behaviour.

#### 4 SYSTEM ERGONOMICS AS A BASIS FOR EVALUATION

A study by Sträter [3] shows that observed occurrences can be analysed according to system ergonomics categories and can be abstracted with an aim to draw conclusions for possible unknown combinations of events. The procedure is as follows. The start is a colloquial description of an erroneous event as it is described in every branch and is, for example, specified by law in the case of the nuclear industry. Such an event is usually described from an individual perspective, using distinct terminology. Therefore, in the next step, the description of the event is translated into a special interim language, which uses a categorizing system derived from system ergonomics in connection with the idea of the closed-loop man-machine system (see Fig. 1). This procedure is illustrated in Fig. 4.

It can be shown that various kinds of error and all conditions for error can be recognized by this system. In addition, error models reported in the literature can

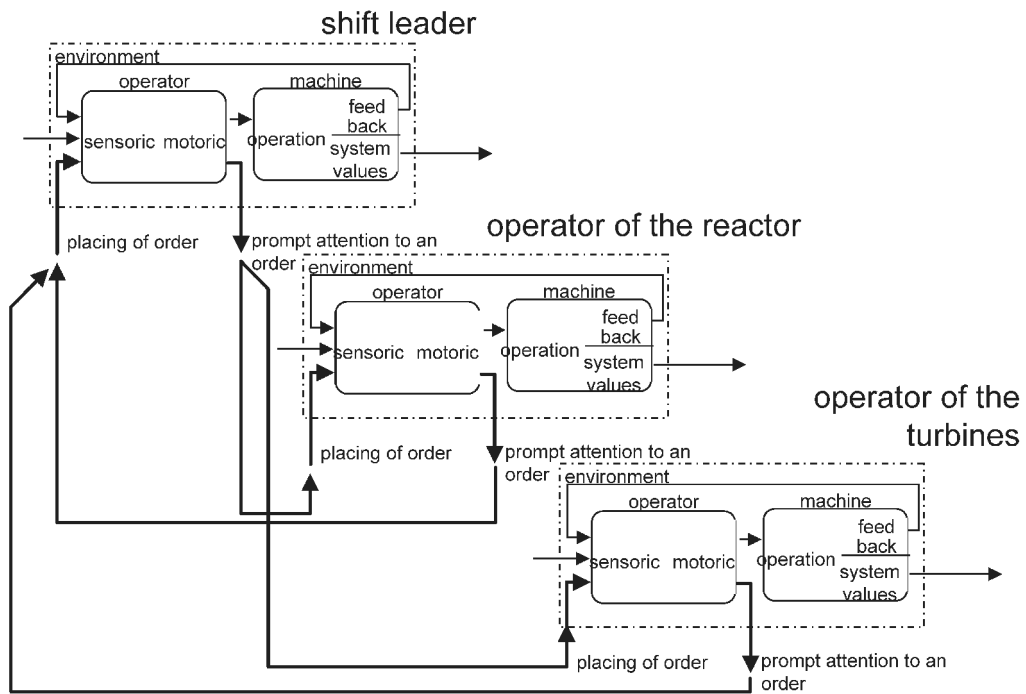


Fig. 3 Description of a complex working system

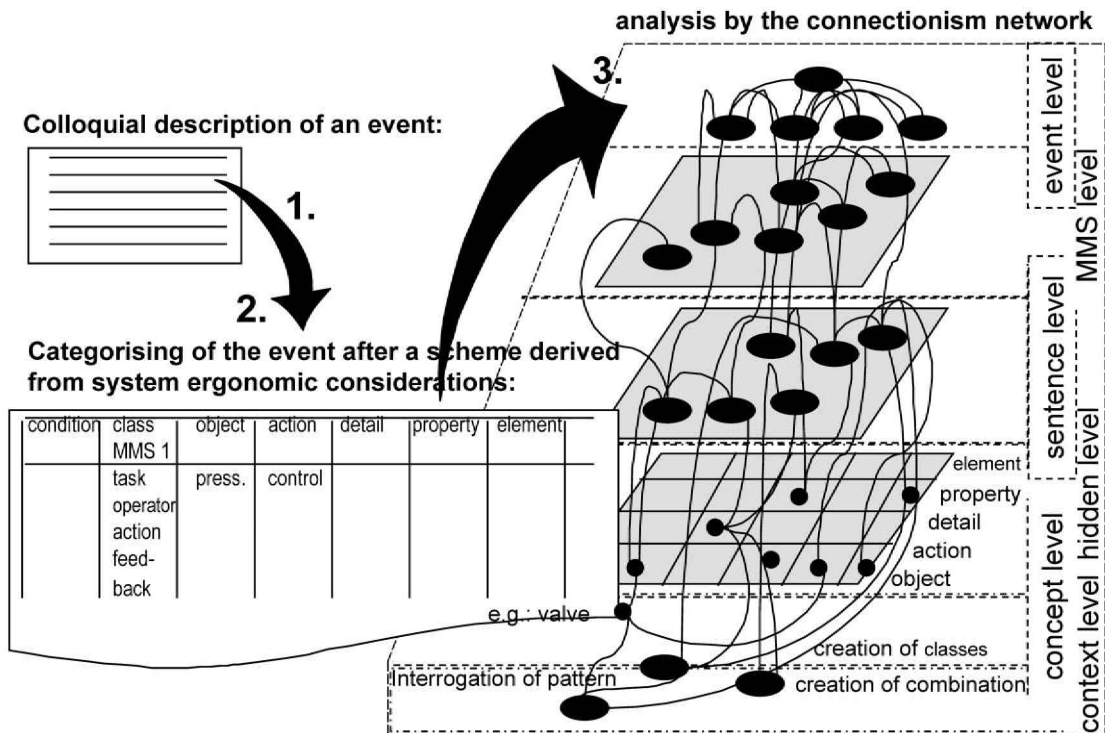


Fig. 4 Analysing events using the CAHR system

be described by this system as well. However, if all possible combinations were to be used to evaluate the results of such an investigation, it would lead to a 'combinatorial explosion'. Therefore, methods of the KI techniques have been used to reduce volume during the analysis. This is achieved by the so-called 'connectionism

network', which represents a certain combination of methods of neuronal models and of the fuzzy control theory. The processing within a connectionism network means that at first an input information on the so-called 'context level' activates knots, very similar to the electrophysiological activation of neuron cells. The pattern of

the input activities is then translated through one or more hidden layers to the output level, called the 'event level'. During the evaluation phase different weight factors are determined that describe the importance of the various connections. This is actually done by feeding the system with as many colloquially described events as possible. The activation of the knots on the output level represents the answer to the specific question that initiated the input pattern. The advantage of the connectionism model lies in the processing of incomplete information, as is the custom with colloquial descriptions. It is then possible that the evaluation algorithm can learn and find similarities between the transfer of results of different branches, something often considered to be problematic. The system described here is called CAHR (connectionism assessment of human reliability).

CAHR can be used in two different ways. One way is to transform a question through use of the network from bottom to top. The result is a quantitative statement concerning the frequency of occurrence of certain terms in the context of a certain question containing the event of interest. By the probabilistic model of Rasch [4] the relative frequencies of this analysis can be seen as indicators of the general probabilities. By a special mathematical model, these probabilities can be estimated from the observed relative frequencies. Therefore it is possible to receive probability values of human errors directly from the observed events.

The other method of using CAHR is to evaluate an interrogation from top to bottom. This leads to qualitative statements concerning the terms that are important in connection with a certain event. Use of this second method produces more relative information regarding the circumstances leading to error-like situations.

The detailed analysis achieved with CAHR shows that the potential for error is more likely to be determined by the complexity of the situation rather than by insufficient availability of time, as is the assumption of the human cognitive reliability (HCR) procedure [5]. However, in critical situations, limited time and complexity are interchangeable, so the simple model indicating insufficient time also leads to acceptable results.

The second method of the CAHR analysis, i.e. the top-to-bottom way, leads to qualitative results from which conclusions for improvements can be drawn. For example, 30 conditions could be identified that lead to human errors. These conditions can be considered to be rules by which improvement of human reliability can be achieved. The most important are:

1. *Simplification*. There exists an individual trend to simplify subjectively a complex situation. Therefore the simplification of tasks and technical layout can prevent this tendency.
2. *Avoiding confusion*. Often errors in the area of repair and maintenance occur by confusing tubes and electrical connectors. This can be avoided, for example, by

not drilling screw holes equidistant apart on flanges or by using asymmetric designs for connectors.

3. *Design, clearness and precision*. Because of the tendency to ignore redundant information, important information can often be neglected. This can be avoided by using clear and distinctive design premises.
4. *Indication and identification*. Feedback is often cryptic or not immediately understandable when the designer takes it for granted, for example, that the information is familiar to the operator based on his or her education.
5. *Arrangement*. An ergonomically correct arrangement of indicators and control elements depends on the task. This is a latent error-like situation in fixed wired-up consoles, which can be fundamentally avoided through the use of software-supported systems.

The system ergonomics classification enables cognitive errors to be identified, especially errors resulting from confusion. In this context, cognitive errors only occur when the situation is neither completely usual nor completely unusual, i.e. when a situation is not ambiguous. The CAHR analysis serves in the management of current aims first to identify singular errors and then to avoid these errors in the future using certain 'locking procedures'. Of course, errors that have yet to be identified have the potential to occur. However, the application of system ergonomics rules leads to improving strategic error management.

If there is a specific problem concerning a certain event, answers to the following questions can be arrived at through the use of this system:

1. Under what circumstances do individuals fail to observe regulations?
2. What kind of errors can be expected in certain working situations?
3. What contributing factors are of importance and how can the situation be improved?

Figure 5 lists circumstances and their level of importance when compared with erroneous actions found by the CAHR system (as of yet 232 events have been investigated). The values in this diagram make it clear that time pressure is of less importance than cognitive-orientated aspects (less knowledge, conscious simplification and unconscious perturbation). It is also to be noted that, besides the quality of instruction, ergonomic factors (possibility of perturbation) and organizational factors (organizational preparation of the task) are also dominant factors.

In addition to these kinds of error, the following can be established. Errors occur when the operator wishes to overcome an interruption but owing to technical circumstances is not able to do so and also when the possibility of taking action is not generally at hand. Causal factors of influence can be observed as further qualitative results:

cognitive error:	Importance (frequency of error/frequency of occurrence)	
Instruction is correct but in the technical system possibilities of perturbation exist	0,45	ergonomic aspects
completeness of instruction (quality of instruction)	0,43	
Existing information was not used by the operator (less knowledge)	0,41	pedagogic aspects
Simple routine actions	0,33	
Organizational preparation of the task	0,19	organisational aspects
Marking of operating funds	0,18	
Unclear instructions	0,16	
Conscious simplification of a situation in order to reach the goal (goal reduction)	0,15	
Unconscious perturbation during information processing ("less attention")	0,14	
Time pressure	0,13	

Fig. 5 Circumstances for events with faulty actions despite existing instructions

1. *Missing feedback* plays a central role in human reliability. If there is a lack of feedback, then in 84 per cent of cases an error of execution occurs and in 55 per cent a task error is connected to it.
2. *Unclear and misleading instructions* are the second important cause for errors. Contrary to the missing feedback, however, deficiencies in instructions can be compensated for by the knowledge of the operator.
3. *Inadequate organizational aspects* point to deficiencies of the management. These deficiencies are concerned with a lack of foresight concerning aspects of classic ergonomics in the area of human adapted design of the task and environment, operator-related ergonomics as feedback and task, and organizational aspects like placing an order and prompt attention to an order.

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