European Agency for Safety and Health at Work

EUROPEAN RISK OBSERVATORY

EN

LITERATURE REVIEW

The human-machine interface as an emerging risk

European Agency
for Safety and Health
at Work

LITERATURE REVIEW
THE HUMAN-MACHINE INTERFACE
AS AN EMERGING RISK

Authors:
Topic Centre Risk Observatory:
Eva Flaspöler, Angelika Hauke, Preethy Pappachan and Dietmar Reinert, BGIA, Germany
Tobias Bleyer, Nathalie Henke, Simon Kaluza, Angela Schieder and Armin Windel, BAuA, Germany
Waldemar Karwowski, CIOP, Poland
Simo Salminen, FIOH, Finland
Jean-Christophe Blaise, Laurent Claudon and Joseph Ciccotelli, INRS, France
Lieven Eeckelaert, Marthe Verjans, Karen Muylaert and Rik Op De Beeck, Prevent, Belgium

In cooperation with:
The following sections are based on a questionnaire survey of experts in ergonomics:
Brigitte-Cornelia Eder, AUVA, Austria
Chris Honings and Freddy Willems, Prevent, Belgium
Michael Schaefer and Michael Huelke, BGIA, Germany
Jouni Lehtelä, FIOH, Finland
Javier Badiola and Clotilde Nogareda, INSHT, Spain
Peter Ellwood, HSL, UK
Ian Thomson and Trevor Shaw, HSE, UK

Table of contents

Foreword

The evolution of society and the changing world of work bring new risks and challenges for workers and employers. In this context, the European Risk Observatory (ERO) of the European Agency for Health and Safety at Work (EU-OSHA) conducted four expert forecasts, based on a Delphi methodology, to anticipate new and emerging risks related to occupational safety and health (OSH) risks. One expert forecast was conducted for physical, one for chemical, one for biological, and one for psycho-social risks.

Various emerging factors were identified by the expert forecast on physical risks related to, for example, musculoskeletal disorders, noise, vibration, thermal risks, etc. Among these, the following ergonomics or human factors risks were also identified as emerging:

- Multi-factorial risks (e.g. in call centres: combined effects of poor ergonomic design, poor work organisation, mental and emotional demands)
- Complexity of new technologies, new work processes and human-machine interface (HMI) leading to increased mental and emotional strain
- Poor ergonomic design of non-office visual display unit (VDU) workplaces
- Poor design of HMI (excessively complex or requiring high forces for operation)

The opinion of the forecast's experts underline the crucial role played by ergonomics and especially cognitive ergonomics in ensuring health and safety at the workplace. Interaction with – and indeed dependence on – technology is increasing in almost all occupational fields. Given that poor HMI can have serious consequences, such as occupational accidents and diseases, including stress, its proper inclusion in design equipment and workplace is of utmost importance.

Further evidence of the importance of HMI can be found in the EU-OSHA report on "*Priorities for occupational safety and health research in the EU-25*", which identified research on adequate ergonomic design, including HMI, as a priority for the European Union.

Moreover, the revision of the Machinery Directive[1] focuses attention on ergonomics. It states that "*under the intended conditions of use, the discomfort, fatigue and physical and psychological stress faced by the operator must be reduced to the minimum possible, taking into account ergonomic principles such as … adapting the man/machinery interface to the foreseeable characteristics of the operators.*" (Page 14, 1.1.6 Ergonomics).

This report aims to raise awareness of the importance of adequate HMI as a vital factor for ensuring workers' occupational safety and health.

EU-OSHA would like to thank BGIA as lead authors, the other Topic Centre Risk Observatory authors and the additional experts for their contribution to this report.

The Agency is grateful to its focal points for their valuable comments and suggestions.

European Agency for Safety and Health at Work

---

[1] Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery

1 Introduction

1.1 Human-machine interface (HMI) as an ‘emerging risk’

Industrialisation brought widespread use of tools and machines to the workplace and these have steadily grown in number and complexity since that time. Design was driven by technical requirements and rarely took account of the needs and characteristics of the operators. As a result, workers often had to adapt to processes determined by the technical system. Only in the middle of the 20th century did the operator gain more attention in the design process of work systems, leading to changes in design paradigms, culminating over recent decades in a shift to user-centred design.

With the introduction of ergonomics, or human factors, workers’ health and safety has been improved by adapting machines and tools to humans’ skills, limitations and anatomy. Furthermore, systems of work are increasingly constructed as a socio-technical system consisting of workers, tools, tasks and work contexts (Sarodnick & Brau, 2006). As use of machines – especially computers – increases, so the HMI becomes more prevalent across all fields of work.

Ergonomics is a broad discipline, which ranges from use of anthropometrics in design of equipment and workplace to cognitive ergonomics and the concept of “usability”. The focus on user-friendly design of technical systems, machines and tools has increased with the recognition that such systems provide effective support for users, improving not only their effectiveness and efficiency, but also satisfaction (Sarodnick & Brau, 2006). Nevertheless, efficiency and productivity gains are far more common as a reason for applying ergonomic principles compared with employees’ wellbeing, despite the longstanding link between ergonomics and safety and health at work (Schmersal, 2005).

In 2005, EU-OSHA completed four expert ‘forecasts’ of new and emerging risks in the physical, biological, chemical and psychosocial areas. For their task, the experts used the following definition:

- *The risk was previously unknown and is caused by new processes, new technologies, new types of workplace, or social or organisational change; or*
- *a long-standing issue is newly considered as a risk due to a change in social or public perceptions; or*
- *new scientific knowledge allows a long-standing issue to be identified as a risk.*

The risk is increasing if:

- *the number of hazards leading to the risk is growing; or*
- *the likelihood of exposure to the hazard leading to the risk is increasing (exposure level and/ or the number of people exposed); or*
- *the effect of the hazard on workers’ health is getting worse (seriousness of health effects and/ or the number of people affected).*

The expert forecast on emerging physical risks (EU-OSHA, 2005) identified the following issues related to ergonomics:

- *Multi-factorial risks (e.g. in call centres: combined effects of poor ergonomic design, poor work organisation, mental and emotional demands)*
- *Complexity of new technologies, new work processes and HMI leading to increased mental and emotional strain*
- *Poor ergonomic design of non-office visual display unit (VDU) workplaces*
- *Poor design of HMI (excessively complex or requiring high forces to operate)*

Research and practical experience show that systems which neglect ergonomics, particularly HMI, are more likely to give rise to occupational diseases, operating errors and accidents. Less visible, but also highly significant are the associated financial costs associated with wasted working time, user frustration, poor corporate image, etc. Poor ergonomic design of products that leads to client dissatisfaction also results in lost sales and damage to companies’ image (Dahm, 2006).

In general, the literature focuses on three different starting points in order to ensure safety, health, efficiency, and productivity: the human being, the machine, and the environment. At the same time, these are also identified as risk sources which may jeopardise safety and productivity at work. Human-machine interactions are seen as error-prone and the environment may give rise to unpredictable situations which lead to danger (Montenegro, 1999). When designing an adequate HMI, the working environment as well as the specific properties and qualities of humans and machines must be taken into account. As regards automated processes, machines are more suited than humans to controlling processes, whereas thanks to their creativity and intuition human beings have the flexibility to cope better with unexpected or unforeseen situations (Montenegro, 1999). It is very important, therefore, that tasks are divided appropriately between the human operator and computer-operated technical system, according to the working situation and working environment.

Researchers also agree on the importance of taking sufficient account of operators when creating usable and safe systems as it reduces the likelihood of errors in the design process. Koller, Beu & Burmester (2004) have shown that the operator's opinion on HMI is as important as the tasks for which the product will be used and the technical, physical, and organisational conditions in which the system is to be implemented. Involvement of users in the design process from the start allows adaptation of the end product to the needs of the different target groups of users. Changes identified through operator testing that is carried out only at the end of the design process are usually far more costly to implement than if identified earlier on. A frequently used approach to putting these principles into practice is the "user-centred design process", also known as "usability engineering process" (Koller, Beu & Burmester, 2004), which incorporate feedback loops and evaluation in the HMI design process.

Looking to the future, new HMI challenges will arise as humans work evermore closely with increasingly complex machines and new control interfaces are designed. Recent developments include wearable computers and powered exoskeletons, such as Robot Suit HAL[2], which is already on the market. New interfaces include gesture technology; brain-computer interfaces, which allow control using brain waves; haptic technology (e.g. touch screens); and speech recognition software.

1.2 Scope of this report

The aim of this report is to follow-up the expert forecast on physical risks and to further investigate HMI as an emerging risk. Based on a literature survey, analysis of survey data and a small expert survey, the report explores whether complexity of HMI leads to safety and health risks such as increased mental and emotional strain for users. In so doing, it addresses the following questions: To what extent is user-centred design applied in the world of work? Are there barriers to the application of user-centred design? What HMI-related risks are jeopardising safety and productivity at work? Which methods and standards favour user-centred design and are they applied in practice? Are there groups of workers which are especially affected by poor HMI design?

The scope of the report is mainly restricted to HMI in terms of "machinery" as defined by European directive 98/37/EC (the "machinery directive")[3] and puts only a small emphasis on the human-computer interface, which is a large topic in its own right. HMI includes a broad range of fields that, although relevant to health and safety at work, are beyond the scope of this study.

Human-computer interaction (HCI) comes under the umbrella of HMI, but it is a well-developed research field in its own right that focuses mainly on improving computers' usability. HCI is only covered in this report insofar as a poor HCI can contribute to stress.

Operational or system safety, or reliability engineering, considers how accidents can result from the interaction of different parts of a system with each other and with their environment. Rather than looking at occupational accidents, it is concerned principally with the avoidance of major accidents that can affect large numbers of people, both workers and public. The part played by human operators in systems – especially those related to major hazards, such as chemical plants, nuclear facilities, airliners, etc. – is affected to a great extent by the HMI. Research fields such as human error and human reliability analysis consider HMI, but are beyond the scope of this report, which is concerned with safety as it affects the operator.

HMI can also be taken to include physical ergonomics and the prevention of musculoskeletal disorders; but again, this is a large field in its own right that has been well covered by EU-OSHA in previous studies[4].

---

[2] http://www.cyberdyne.jp/english/index.html

[3] Directive 98/37/EC of the European Parliament and of the Council of 22 June 1998 on the approximation of the laws of the Member States relating to machinery as amended by Directive 98/79/EC

[4] http://osha.europa.eu/en/topics/msds; http://osha.europa.eu/en/riskobservatory/risks/forecasts/index_html/physical_risks/

1.3 Definitions

1.3.1 Machinery

The term “*machine*” has various definitions; some are sophisticated, others quite simple. The point at which tools or auxiliary means can be characterised as machines is complicated and leads to complex descriptions. Examples of broad definitions are those given by the Concise Oxford Dictionary:

”*An apparatus using or applying mechanical power, having several parts each with a definite function and together performing certain kinds of work.*”

And Charwat (1992):

“*[An] umbrella term for all technical devices which are used by humans for a specific purpose. Machines can be vehicles, devices, aggregates/units, computer or their combination (e.g. automated systems)*” (p. 285).

At the other end of the spectrum is the precise definition used in the machinery directive, which was enacted to protect users against risks caused by machinery:

- “*… an assembly of linked parts or components, at least one of which moves, with the appropriate actuators, control and power circuits, etc., joined together for a specific application, in particular for processing, treatment, moving or packing of a material,*
- *an assembly of machines which, in order to achieve the same end, are arranged and controlled so that they function as an integral whole,*
- *interchangeable equipment modifying the function of a machine, which is placed on the market for the purpose of being assembled with a machine or a series of different machines or with a tractor by the operator himself in so far as this equipment is not a spare part or a tool;…*” (Directive 98/37/EC, p. 5).

Among the devices excluded from this directive, are:

- “*machinery whose only power source is directly applied manual effort, unless it is a machine used for lifting and lowering loads …*
- *… means of transport, i.e. vehicles and their trailers intended solely for transporting passengers by air or on road, rail or water networks, as well as means of transport in so far as such means are designed for transporting goods by air, on public road or rail networks or on water. Vehicles used in the mineral extraction industry shall not be excluded …*” (Directive 98/37/EC, p. 5).

Although the machinery directive excludes computers from its definition, this is not the case for researchers in the field of human factors, ergonomics, and HMI, as stated by Carey (1998) “*The human factor engineer is concerned with many machines other than the computer…*” (p. 27).

1.3.2 Human factors

Asbjørnsen (1994) cited by Einarsson (1999) explains human factors as “*the relationships and interactions between a system and its human elements and between the human elements themselves in a system or its adjacent organisation. The integral of all human factors in a corporation constitutes the corporate psychology. This makes up the corporate culture and the social resources in the corporate competitive position.*”

According to Wickens and Hollands (2000), the concern of the field or discipline called human factors is “*designing machines to accommodate the limits of the human user*”. They further define the elementary objectives of human factors engineering as the reduction of error, the increase of productivity and the enhancement of “*safety and comfort when the human interacts with a system*”.

1.3.3 Human-machine interface

Descriptions of HMI can be broad, such as that given by Tutherow in Lipták (2002): “*Although it can refer to any type of interface device, the term HMI usually refers to the display, computer, and software that serve as the operator’s interface to a controller or control system.*” (p. 288).

More precise definitions are provided by Baumann and Lanz (1998) as well as by Charwat (1992). They describe HMI as the part of an electronic machine or device which serves for the information exchange between the operator/user and the machine/device. HMI consists of three parts which are (1) operating elements, (2) displays, and (3) an inner structure. The *inner structure* compasses hardware and software (electronic circuits and computer programmes). *Displays* show and transfer information about the machine to the user (for instance by means of graphical displays) and *operating elements* transfer information from the operator to the machine via for instance push buttons, switches, adjusting knobs, etc..

1.3.4 Human-machine interaction

Humans and machines interact and affect one another; however, compared to communication between humans, the media available are restricted only to the above mentioned displays and operating elements. In this context humans can only use physical input devices, such as buttons, touch-screens, keyboards, or mouse. For their part, machines can give information visually (e.g. as pictures and characters), acoustically (verbal or nonverbal) or physically (e.g. vibration).

Complex interaction between humans and machines is limited by the fact that whereas humans have natural intelligence, which enables us to interpret situations according to the context, this ability is absent in most machines and very restricted in even the most advanced. In general, software does not allow machines to adapt to unforeseen conditions, so computers are limited in their actions and cannot adapt to given situations. Nonetheless, humans often expect the machine to communicate in the same way as they do and get frustrated or angry when it does not (Dahm, 2006).

1.3.5 Ergonomics

Ergonomics deals with human work and the optimal adaptation of work to the properties and skills of the humans involved in the working system. Thus, the focus of ergonomics is the human and his needs in fulfilling his tasks; including the ‘need’ to be protected from injury and ill health. In order to protect workers, ergonomists develop new methods and design the working environment in a way that supports workers in achieving their objectives effectively and efficiently (Dahm, 2006). This definition already shows the close relationship between ergonomics (the anatomically adapted design of tools/machines and supplies for work and of working procedures), safety at work and productivity (Schmersal, 2005).

While ergonomics traditionally focused on anthropometric design of machines, cognitive ergonomics became important in the mid 1970s. The field of cognitive ergonomics covers communication aspects, for example, in the interaction with machines (e.g. software ergonomics) (Charwat, 1992).

1.3.6 Usability

“Usability” is defined in the norm ISO 9241-11[5] as the “*extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use*" (p. 2). Thus, usability is an essential part of (cognitive) ergonomics, which permits humans to use machines and tools efficiently, effectively and in a way that is satisfying (Sarodnick & Brau, 2006).

---

[5] ISO 9241-11:1998 Ergonomic requirements for office work with visual display terminals (VDTs) Part 11: Guidance on usability

2 Who is exposed to HMI-related risks?

2.1 Increasing importance of HMI

The use of complex machines, processes and systems is increasing in all sectors, but there is also some evidence that the pace of change is slowing. The drive for automation and computerisation stems principally from increasing labour costs and from higher quality requirements and standardisation. This development should be seen positively so long as it results in better products and does not affect workers' health.

Production technology, particularly manufacturing machines in the metal industry, is especially affected by increasing complexity and increasing use of complex machines, processes or systems. An increase in operators' mental workload and consequently in the risk of errors, means that HMI is of particular relevance to high-risk industries, such as the chemical, electric or nuclear energy industry and transport. Automation and increasing complexity mean that control room operators have to handle complex data and alarms and to take safety-critical decisions under the pressure of unexpected and rapidly changing hazardous situations.

In general, technical installations are becoming more complex in industrial processes ranging from automobile-related industries to biotechnology. Increased complexity can be found in, for example, cranes, elevators and other transport systems, self-steering buses, autonomous trains, vehicle with extensive driving aids, such as adaptive cruise control and autonomous braking and parking.

Other HMI-susceptible areas include workplaces related to operating and monitoring (especially if the process itself is not visible), such as waste management and disposal engineering machinery, public and administrative systems, maintenance sector, equipment used in the electrical energy sector, handling systems and data process installations.

2.2 Number of machine users

Eurofound's[6] fourth European working conditions survey (EWCS) carried out in 2005 shows that one in four jobs involve working all, or almost all, of the time with computers, however, no comparable figures exist for machines.

At national level, information is available from the 2005/2006 German BIBB-BAuA survey of 20,000 employees[7]. This showed that 8.2% of respondents work with machines (excluding computers, as defined in directive 98/37/EC), which when applied to the whole working population of Germany, indicates that 5.5% of workers, or 1.82 million, work with machines.

Working conditions of machine users were investigated in the BIBB-BAuA survey using a sub-sample (*n*=1104) of machine users and the results are described in the following sections.

2.3 Type of machine and size and sector of enterprise

As can be seen in Figure 1 below, 70% of the BIBB-BAuA sample used one of three types of machine: "automatic", "manually driven" or "machines, plant (in general)".

---

[6] European Foundation for the Improvement of Living and Working Conditions www.eurofound.europa.eu

[7] BIBB/BAuA – Erwerbstätigenbefragung 2006 www.bibb.de/de/wlk21738.htm

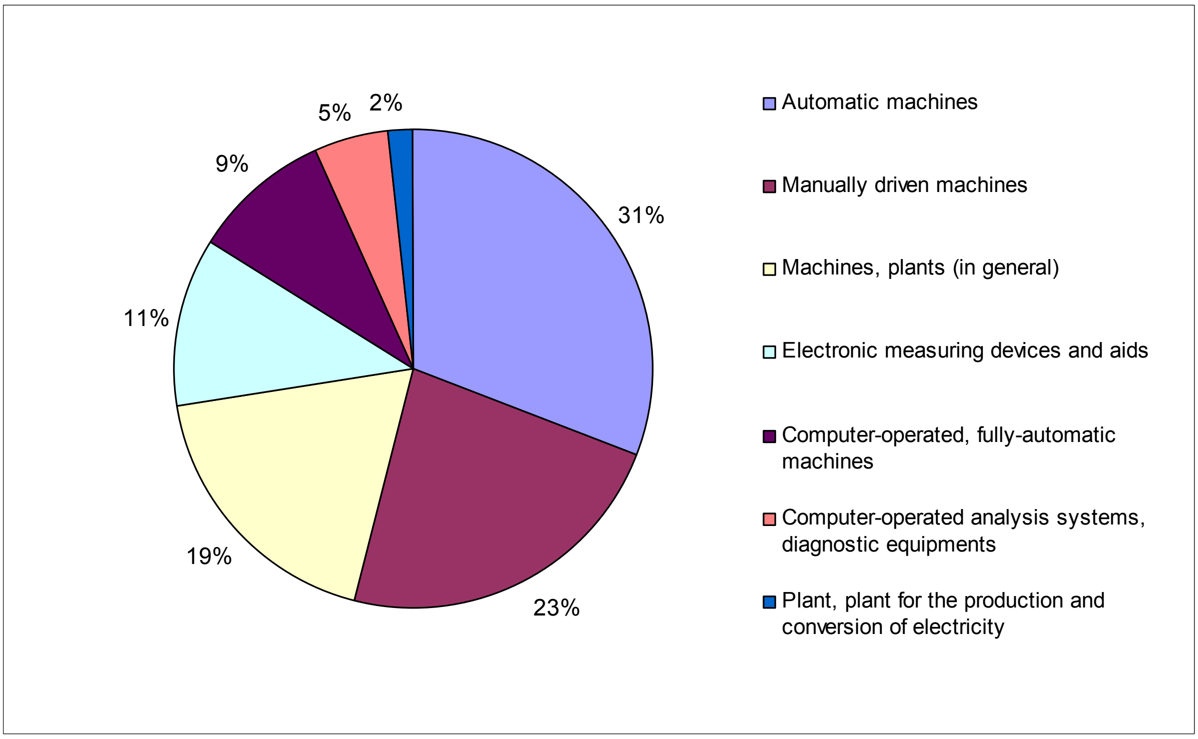


Fig. 1: Type of machine used (machine users' sample, BIBB-BAuA survey 2005/2006)

Most machine users work in companies with 10 to 49 employees (28.6%), in companies with 50 to 249 employees (24.7%), and in companies with up to 9 employees (18.7%). The share of machine users working in companies with 10 to 499 employees is slightly higher than in enterprises in general.

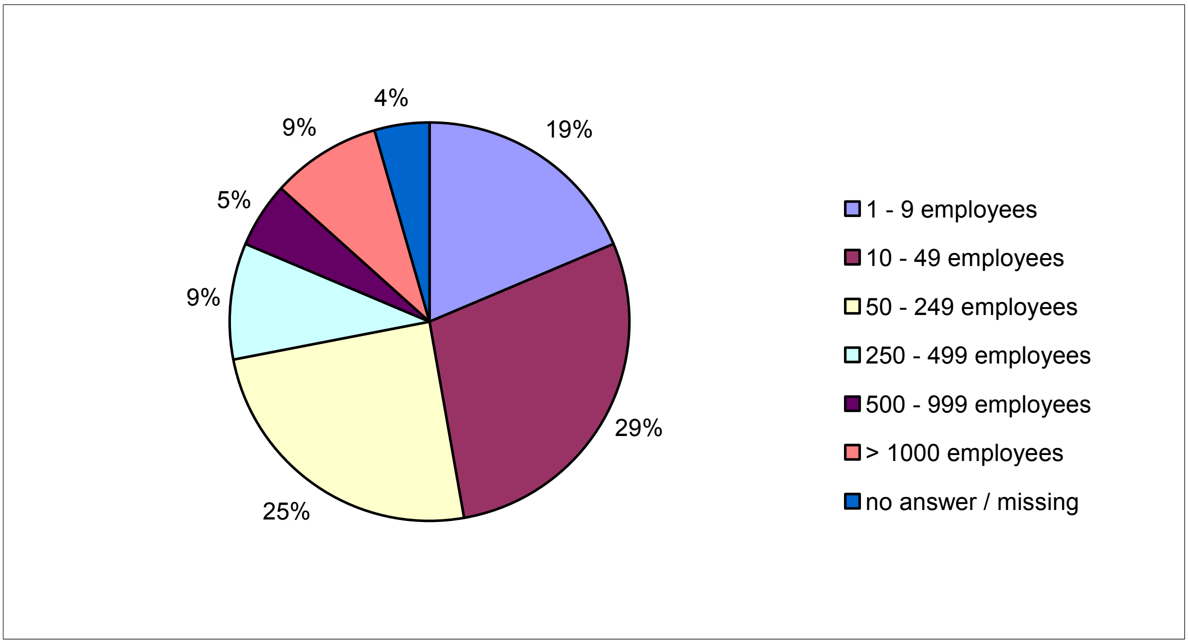


Fig. 2: Size of companies employing machine users (machine users' sample, BIBB-BAuA survey 2005/2006)

Data from Eurofound's 2005 EWCS show that – as would be expected – the largest proportion of workers whose pace of work is dictated by a machine are in manufacturing (41%). The next highest sectors, with approximately a quarter of workers affected, are construction, transport and communication, and agriculture (see figure 3 below).

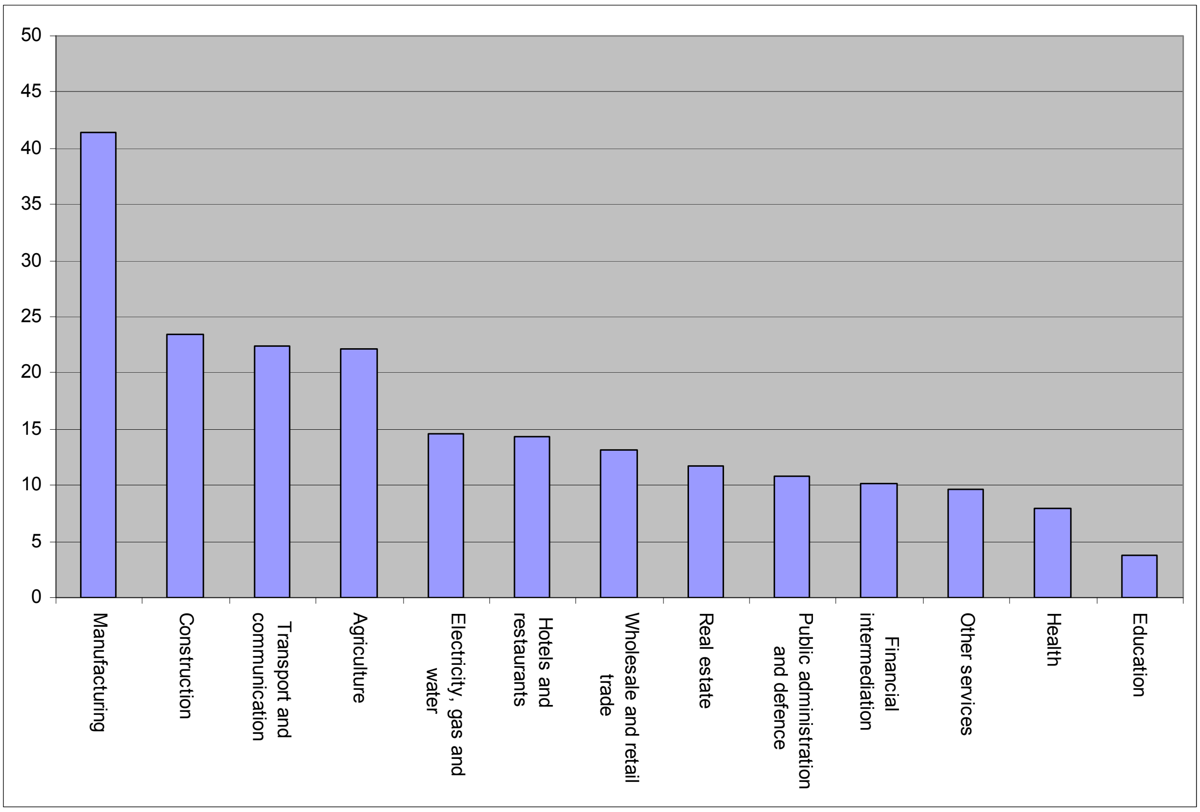


Fig. 3: Proportion of workers whose pace of work is dictated by a machine (Eurofound EWCS 2005)

2.4 Sex, age and skill level

In the BIBB-BAuA sample, more men than women (65.2% vs. 34.8%) work with machines.

The age distribution in the group of machine users is equivalent to the age distribution in the general working population, however, research indicates that age and especially experience of machine operators is an important factor in accident risk. According to Backström and Döös (1995), about three quarters of the victims had one year or even less experience. Other studies estimate that approximately one quarter of the injured persons have three months or less experience, another quarter had four months to one year of experience and almost half of the victims had two years or more experience (Döös, Backström and Sundström-Frisk, 2004).

Having gained a good understanding of how a machine works, experienced operators are at least risk of suffering an accident as a result of HMI. In contrast, workers who work with the machine just occasionally and are less likely to receive instruction or training are at high risk. This group includes maintenance workers, temporary workers, home-workers, tele-workers, seasonal workers, as well as operators of machinery for hire. Similarly, when a new work process or technology is introduced – especially if done so too quickly – the risk of problems associated with HMI increases.

Older workers are more likely to experience problems in working with new technology. They may find it difficult to change their habits and may need specific training and coaching. HMI should be tailored to their abilities. However, it is not only older workers who may encounter difficulties using new technology. Many people, for example, either lack experience of using computers or simply do not want to use them. As a result, these workers are more reserved and hesitant when interacting with computers and are more at risk from inadequate use of HMI.

Among those working at machines, the proportion of unskilled and semi-skilled workers (26.3%) is higher than in the total population (14%). In the sample, 40% of the machine operators are skilled workers, 12.7% are qualified employees/civil servants, 6.1% are unqualified employees/civil servants, 4.5% are executive staff/civil servants and 1.6% are master craftsmen/head foremen. For 9%, no classification is available. Additionally, some workers may be at greater risk from a poor HMI because other limitations such as disability, poor knowledge of the local language, low level of education, or lacking experience of technology and complex systems.

Greater specialisation means that fewer workers are able to understand how to work with the specific complex machine. Maintenance activities, in particular, pose a challenge as a lot of complex systems need human assistance or intervention. The design of many machines considers only operation under normal conditions; as a consequence, when maintenance needs to be carried out, risks related to such complex systems are not predictable and can be of different nature.

Furthermore, the study found out that employees working with machines are mostly full time workers (79.5% vs. 20.5% part-time workers). 45.9% of these full time workers work between 40 and 47.9 hours a week. Regarding their working contracts (fixed-term and indefinite) percentages are comparable with the entire population.

According to Döös and Backström (1994) working in hazardous areas of automated machines puts workers at increased risk. They state that around two-thirds of injured workers sustained from automated machines are production workers or operators, whereas maintenance staff only makes up 10% of the injured workers.

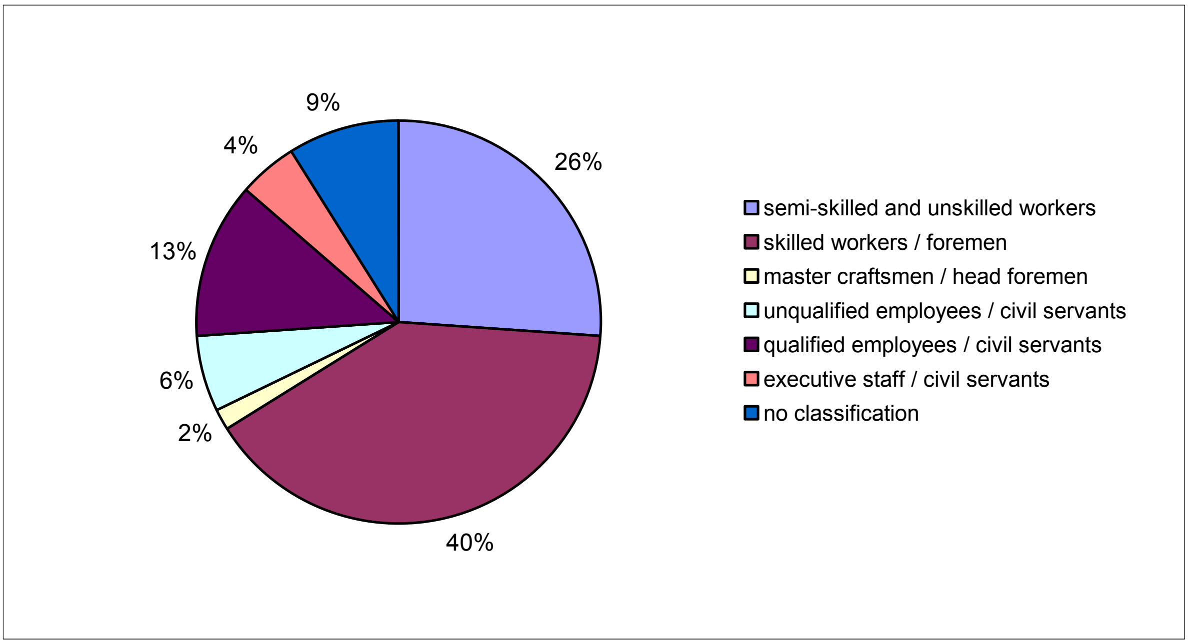


Fig. 4: Skill level of machine users (machine users' sample, BIBB-BAuA survey 2005/2006)

2.5 Working conditions

The BIBB-BAuA data suggest that, in general, working conditions with respect to ergonomic aspects are poorer for machine users than for the total population (see Figure 5 below). Compared with the general working population, machine users are more exposed to repetitive work, working in an upright standing position and carrying heavy loads.

Fig. 5: Machine users exposed ‘sometimes’ or ‘often’ to selected OSH risks compared with the total working population (BIBB-BAuA survey 2005/2006)

Figure 6 below shows that machine users are more likely than the general working population to be exposed to fumes, dust, gas, vapour, cold, heat, wet, draughts, noise, dangerous substances, radiation, oil, grease and dirt, or to have to wear personal protective equipment or clothing.

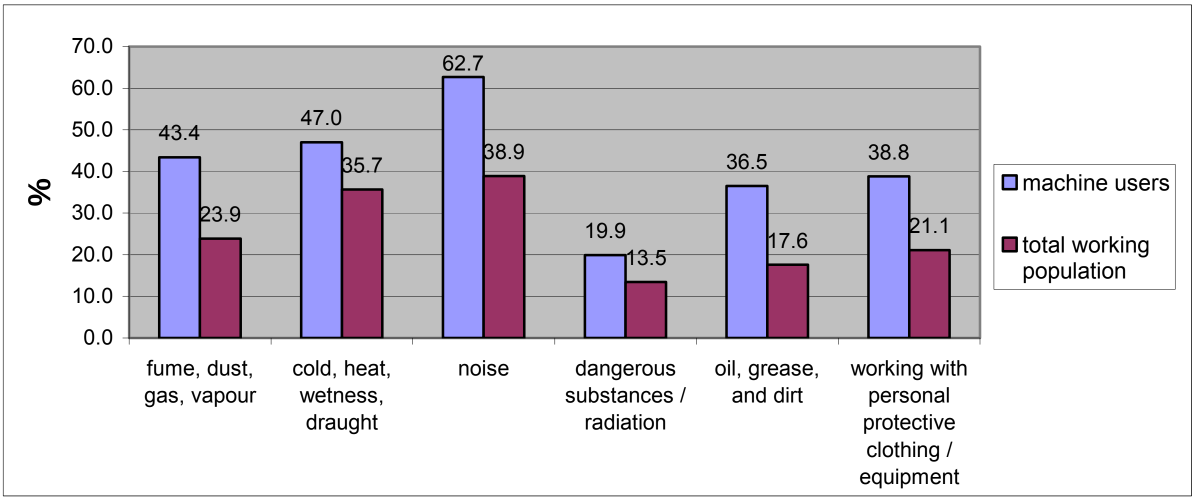


Fig. 6: Machine users exposed ‘sometimes’ or ‘often’ to selected OSH risks compared with the total working population (BIBB-BAuA survey 2005/2006)

Further analysis of the data shows that machine workers are more affected than other workers by whole-body and hand-arm vibration (26.4% vs. 11.3%), high noise levels (35.8% vs. 15.3%) and having to exert high dynamic and static forces (30.2% vs. 17.1%).

With respect to psychosocial risk factors, the data indicates that machine operators have significantly lower decision latitude concerning both work organisation and breaks than other types of worker and slightly lower influence over their amount of work.

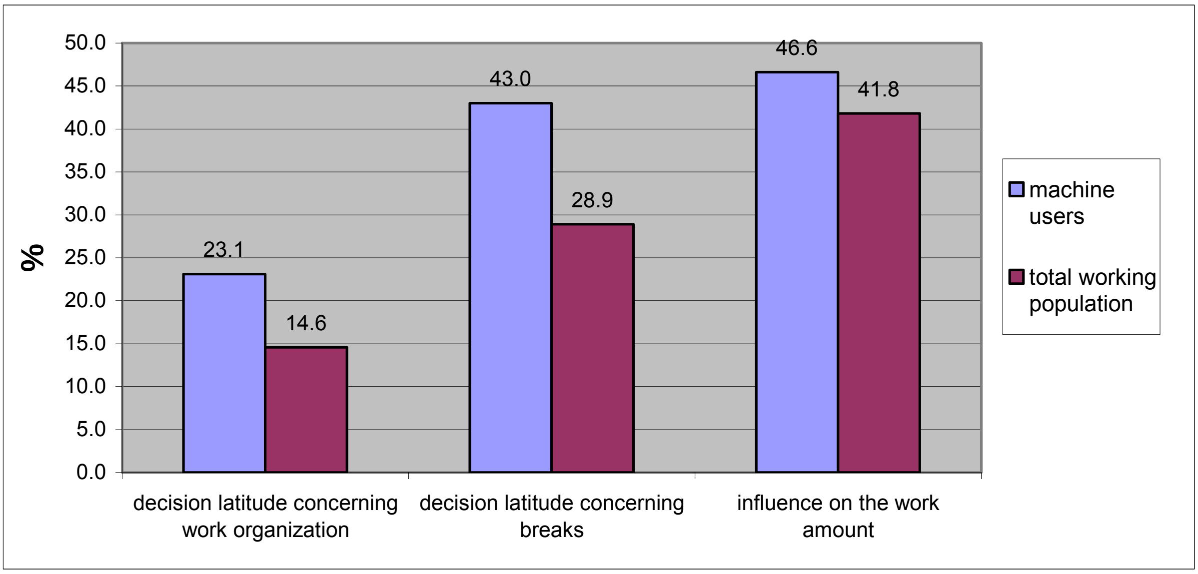


Fig. 7: Machine users 'never' or 'rarely' given decision latitude compared with the total working population (BIBB-BAuA survey 2005/2006)

2.6 Health outcomes

Machine workers are slightly more likely to state that they suffer from back pain than employees in general and are more likely to suffer from pain in their arms and hands, knees and legs or feet. They are also more likely to experience hearing problems such as occupational deafness or tinnitus. In contrast, they are slightly less likely to suffer from headaches or pain in the neck and shoulder than the rest of the working population, where the influence of prolonged working with VDUs can be seen.

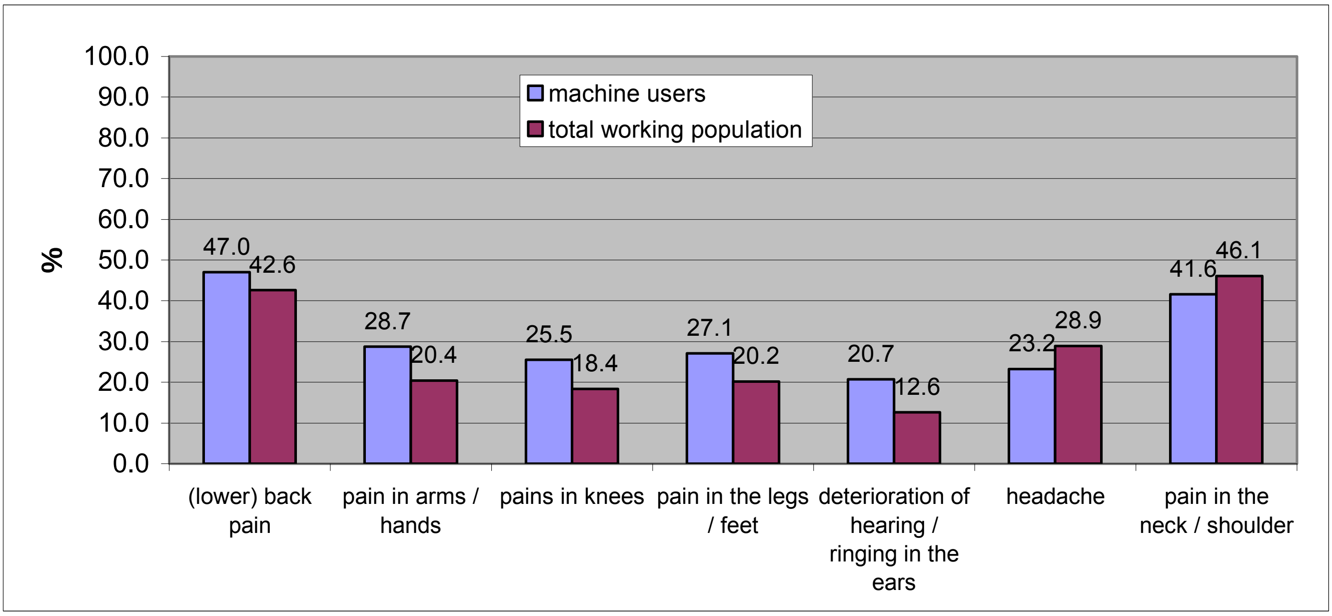


Fig. 8: Machine users' health complaints in comparison to the total working population (BIBB-BAuA survey 2005/2006)

3 Importance of HMI in relation to OSH

3.1 Introduction

Greater automation can have the following consequences for workers' health and safety:

- Psychosocial and musculoskeletal problems caused by reduced physical activity, more static postures and higher mental work load (e.g. when monitoring and controlling); less privacy at work (as technology allows closer and more intrusive supervision); and more decision-making problems.
- Increased risk of accidents resulting from human errors; usually affecting the user, but – especially in the case of high-risk industries - having the potential for serious consequences beyond the operator to include fellow workers, the wider community and environment.

Technical progress over the last 50 years means that production processes are using machines which are increasingly powerful in terms of speed, quality, and flexibility (Becker, 2006). This expansion is evident in almost all sectors, but especially so in manufacturing, air industry, construction (e.g. in-cab devices), production sector and healthcare sector (e.g. computer-aided surgery), (EU-OSHA, 2005).

Linked to increasing mechanisation and complexity is a growth in the use of computer-based automated systems in place of human operators to control highly complex technical systems. However, while computer-based systems offer greater reliability and the potential for greater control, they cannot at present match the flexibility of the human operator. It is computers' inability to cope with unforeseen circumstances that makes the human operator indispensable in complex systems. Particularly at times of failure, systems depend on human operators' intelligent, context-based thinking (Reason, 1990, Nachreiner, Nickel & Meyer, 2006).

Technological developments allow a great amount of information to be presented and combined and for many tasks to be carried out simultaneously. Consequently, operator tasks are frequently reduced to those of start up, monitoring and control of processes via digital media. Relatively small errors on the part of the operator have the potential for serious consequences, so additional safety systems are built in, which often result in the operator being overloaded with information. Conversely, changing a job from one of operating machinery to one of monitoring, control and surveillance, can result in it lacking in content and being regarded as boring and monotonous.

The high proportion of employees working with machines or computers means that proper design of the HMI is essential. Poor design of HMI can give rise to occupational diseases, such as stress or musculoskeletal disorders, as well as to occupational accidents. The potential cost to an employer due to reduced productivity, damaged reputation, or users' dissatisfaction is clear.

3.2 Increased levels of mental strain and stress

Automation should result in better working conditions, however, it can sometimes result in control systems that are more complicated to operate and it can change working methods so that demands increase with regard to stamina, time pressure and the pace of work. As automation reduces the number of operators, those remaining are increasingly isolated and have to act and communicate with the help of the new technology. Additionally, their workload may increase and the impact of errors is likely to be greater. The changes in how work is organised mean that teamwork loses importance and operators increasingly have to be experts in many different fields and bear more responsibility; this may increase task variety, but can also increase mental work load.

Poor design of HMI can lead to bad temper and even to negative health effects. For instance, Sarodnick and Brau (2006) report that frustration caused by the computer can lead to depression.

The neglect of human factor design principles in interface design, particularly where it results in system failure, is a major cause of increased mental strain, which can result in stress (Nachreiner et al., 2006). IT problems affect many workers and can clearly contribute to increased mental strain. In a survey of 1,250 UK workers (Ipsos-MORI, 1999), 23% of respondents said they had to interrupt their work on a daily basis due to IT problems and over 10% of those who suffered daily interruptions stated that stress caused by IT strongly affected their relationships at work. 75% of office workers in another study (Oberhuber, 2007) had resorted to violence against their computer.

Nachreiner et al. (2006) give examples of how failure to apply dialogue principles can result in higher mental workload:

- Displays that show a value without giving comparison levels or an interval indicating a range of non-critical values oblige the user to learn and memorise how to interpret the indicated value with respect to hazards.
- Inconsistency with user expectations or common conformities (e.g. if an emergency stop button were to be given a colour other than red).
- Ambiguous information (e.g. abbreviations which may be interpreted in two different ways). Nachreiner et al. (2006) showed that an unfamiliar alarm signal increased mental stress while the operator tried unsuccessfully to identify the reason for the alarm.

Nachreiner et al. (2006) conclude: "*…inadequate ergonomic design of the interaction interface increases control difficulty… or impedes successful control, which is associated with increased mental work load for the operator and increased strain, thus leading to less effective and less efficient process control.*" (p. 23).

3.3 Occupational accidents

According to NIOSH, machine-related injuries were the second leading cause of occupational fatalities in the United States between 1980 and 1995 and between 1992 and 2001, an average of 148 fatal and 318,488 non-fatal occupational caught-in-running-machinery-accidents occurred per year.

In 2000 in Austria, 8% of all occupational accidents occurred at machines, of which 76% were attributed to human error (68% errors in use of the machine and 8% removal of protective devices), 17% to machine deficiency, 5% to malfunction of a machine component, and 2% to modifications carried out on the machine. The removal or tampering with protective devices is often linked to maintenance, cleaning, repairing, and programming (Österreichisches Bundesministerium für Wirtschaft und Arbeit, 2001).

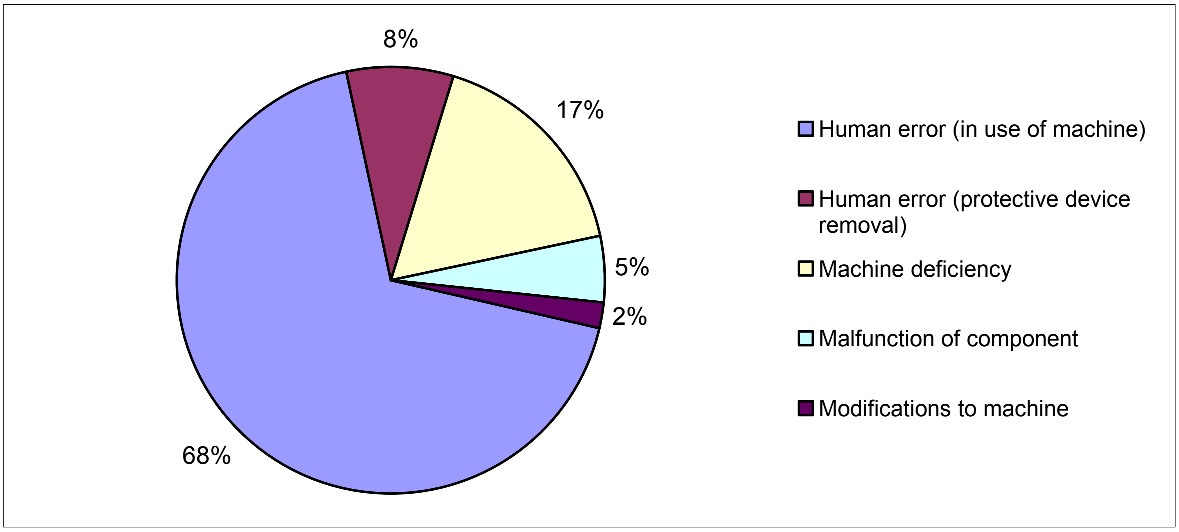


Figure 9 – Causes of accidents at machines in Austria (2001)

Similarly, Backström and Harms-Ringdahl (1984) found that 55% of machine-related accidents resulted from operational failure, whereas 20% were caused by technical failure and 12% by technical as well as operational failure. Other studies, in contrast, attribute higher proportions of accidents to technical failures (Backström and Döös (1997) estimate that 84% are due to machine failure and in an earlier study (Döös and Backström, 1994), the same authors found that 86% of accidents with automated equipment are due to technical causes).

A survey of safety inspectors and employees in the industrial sector by the German statutory accident insurance (HVBG, 2006) showed that tampering with safety devices is a significant problem (37% of cases) and this is supported by research showing that safety barriers are sometimes removed to facilitate the work process (Mattila, Tallberg, Vannas and Kivistö-Rahnasto, 1995). Such safety devices comprise part of the HMI, which if not well designed, may be perceived by operators as a hindrance. Other factors such high production targets or pressure to increase output can contribute to this perception.

Other causes of accidents related to HMI include inadequate operation and maintenance instructions; designs that do not let the operator see the danger zone (Backström & Harms-Ringdahl, 1984; Mattila et al., 1995); and open access to hazardous areas of the work station (Mattila et al., 1995). Unexpected movements of machines (Backström & Döös, 1997; Backström & Harms-Ringdahl, 1984; Mattila et al., 1995) or not stopping a malfunctioning machine system also present accident risks (Backström & Harms-Ringdahl, 1984). Moreover, inadequate workplace design such as an unsafe machine which does not stop when removing safety barriers, an emergency stop which cannot be reached by the operator (Mattila et al., 1995) or confusing control status indicators leading to an unintentional contact with a switch (Backström & Harms-Ringdahl, 1984) can be hazardous for workers.

Since some operators are simply not aware or do not know anything about the functioning of the system they work with (Backström & Harms-Ringdahl, 1984), it is essential that the operator is able to assess the information and to observe the work process (Mattila & Kiviniitty, 1993).

3.4 Human error

Deficiencies in the HMI significantly increase the likelihood of human error, which can easily result in occupational accidents. Much less likely to occur, but with far graver consequences, human error can also result in major accidents or even disasters. It is this latter aspect that accounts for the extensive study of HMI in the fields of system safety, reliability engineering and human reliability analysis.

3.4.1 Definition

From a technical perspective, “human error” can have thee different focuses: it can focus on the cause of an outcome, on an action leading to an outcome, or on the outcome itself (Hollnagel, 1998). In addition, the “human error” can be defined as an omission or inaccurate execution of a planned sequence of mental or physical activities, if the error is not a result of other system components promoting the error. If a certain degree of imprecision is reached, it is likely to result in an undesirable system status (Reuth, 2003).

Human errors can be analysed using taxonomies, which demand different criteria (Reuth, 2003):

- Identification of the underlying *causes* of incidents
- Consideration of human error *mechanisms*
- Identification of *deviation from existing rules / manipulation*
- Understanding *safety relevant consequences*
- Understanding *technical consequences* in production processes
- Consideration of the *frequency* of the incidents
- Identification of the *relevant actions to resolve a dysfunction*

Objective classification of incidents with regard to the taxonomy is essential in order to find out why human error happened and how it can be prevented in future. (Reuth, 2003).

3.4.2 Causes of human error

According to Park (1997), there are three main types of causes of human error:

1. Complexity of task (tasks differ with regard to their demand on mental resources),
2. Situations (some are more likely to lead to errors). The following characteristics increase the probability of human errors:
    - Inadequate workplace design,
    - Inadequate design of work equipment and its HMI,
    - Poor environmental effects,
    - Inadequate learning and working aids and
    - Inadequate safety instructions.
3. Preconditions with regard to human capacities.

The likelihood of human error is affected by individual characteristics such as age, sex, intelligence, perceptive abilities, physical state, patience, experience, knowledge, motivation, emotion, stress and other social factors (Park, 1997). The combination of stress and inexperience can lead to an exponential increase in human errors (Miller & Swain, 1986). These factors are also named *“Performance Shaping Factors”*, as they strongly influence human information processing (Bubb, 1994). External Performance Shaping Factors (age, sex) can be distinguished from internal Performance Shaping Factors (motivation, patience).

3.4.3 Human risk perception and evaluation

The way in which human beings perceive and evaluate risks plays an important role with respect to safe behaviour at work. Human risk perception depends on different perspectives: the source of the risk, the context in which it occurs, and the persons affected (Haller, 2003). If an investigation is carried out into the cause of an accident, this has been found to have a positive effect on risk perception. Döös, Backström, and Samuelsson (1994) found that, as well as improving risk perception among those involved, accident investigations resulted in better knowledge about accident hazards in automated production; made communication easier; and improved information about job routines. Accident investigations also help focus attention on OSH and facilitate the introduction of additional accident prevention measures.

3.4.4 Procedures to analyse and evaluate human reliability

As the costs of human error can be very high, it is important to know what has to be done and what can be done to reduce the probability of human error in potentially hazardous situations (Reason, 1990).

Tools such as probabilistic risk assessment, which are used to assess risks associated with complex technical systems (e.g. chemical plants, nuclear power plants, oil and gas installations), depend on methods such as human reliability analysis to take account of human error in the system

3.4.5 Decision-making

According to Hollnagel (1998), decision-making should in principle follow information processing models. Firstly, alternatives are identified, then they are compared, the best one is selected and finally the consequences of the decision are verified. Field studies show, however, that in practice, people tend to define principle objectives, outline a few obvious alternatives, select a reasonable compromise and then they repeat the task if the results are unsatisfactory. From a safety perspective, this latter approach is not ideal.

Chapter 4 describes design principles and methods which take into account these factors influencing human behaviour with regard to safety and health at the workplace. These methods adapt to the way human beings perceive their environment, process information, and make decisions. Likewise they adapt to human skills and consider their limitations as well.

3.5 Musculoskeletal disorders

Poor HMI is an important risk factor for developing musculoskeletal disorders and this has been linked to the increased incidence of MSDs experienced by industrial nations over the last decades (e.g. EU-OSHA, 2009; Marcus & Gerr, 1996; Skov, Borg & Orhede, 1996). Static postures and repetitive movements contribute, for example, to computer users suffering increasingly from MSDs of the upper limbs (Höhne-Hückstädt, Keller Chandra, Ellegast & Schäfer, 2007). (Gerr, Marcus, Ensor, Kleinbaum, Cohen, Edwards, Gentry, Ortiz and Monteilh, 2002) showed that MSD symptoms in the neck and shoulder occurred among computer users in 58 cases/100 person-years and hand and arm MSD symptoms in 35 cases/100 person-years. Other examples of jobs that are associated with high incidence of MSDs are crane operators and sewing machine operators (Ellegast, Lesser, Herda, Hoehne-Hückstädt, Schwan and Kraus, 2006; Ditchen, Ellegast, Herda & Höhne-Hückstädt, 2005). In order to reduce the risk effectively, ergonomic principles dictate that design of the HMI should include working place, work organisation, working context, and work content (INQA[8]).

---

[8] Initiative Neue Qualität der Arbeit (www.inqa.de/)

4 HMI as a way of improving health and safety

4.1 User-centred design

Design and development of products has shifted from being technology-oriented to user-oriented. Zühlke (2004) describes how, until the 1970s, industrial control devices consisted only of hardware, to which new functions could only be added by developing additional, complex components. In the mid 1970s, the advent of controls based on microprocessors and the availability of inexpensive, repeatable software, made it relatively simple to add new functions. However, the limits to this technology soon became apparent in the form of high software development and maintenance costs and users being overwhelmed by new functions. The so-called 'software crisis' ensued and, partly as a response to this, several ISO and IEEE standards were established.

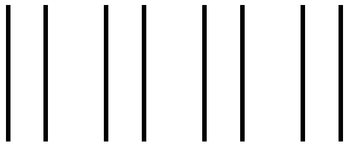
More recently, Zühlke identifies a development, termed an 'operability crisis' or 'usability crisis', whereby users are unable to cope with the complexity of products and do not use all of the functions provided. The HÜMNOS-Project[9], launched in 1995, found that operators typically use only half of a machine's available modes of operation and most users required training of up to three weeks. The main reason for this was found to be the development of operating systems based on a technology-oriented or function-oriented paradigm while the user proceeded with a task-oriented paradigm.

Adoption of user-oriented design and use-ware engineering in the late 1990s is identified by Zühlke as a reaction to the abovementioned operability or usability crisis. The focus of the design process is no longer based solely on functional requirements and what is possible technically, but concentrates on the requirements of the intended user. Users are no longer forced to adapt the way they work to the product; instead it is designed according to their typical work preferences. Use-ware engineering is a multidisciplinary field, which recognises the necessity of bringing together electrical and software engineering as well as industrial psychology, cognitive psychology, and occupational medicine. By using a user-driven and participatory design paradigm, manufacturers take account of user needs from the start of the design process. This approach uses basic psychological and perceptual principals such as the so-called "Gestalt Laws" in product design and particularly in visual interface design.

4.1.1 Gestalt laws/principles

Yee (2002) points out, that graphical user interfaces often rely on associations between graphical elements like labels, checkboxes and lists. Their positioning is essential for the correct allocation of command descriptions and the buttons that complete it. Therefore, Yee (2002) recommends application of the Gestalt principles of perceptual grouping in user interaction design.

Gestalt psychology describes principles of perception which determine the way in which objects are perceived. Gestalt laws or principles do not act in isolation, but rather tend to influence each other, so that the final perception is a combination of all of the Gestalt laws acting together.

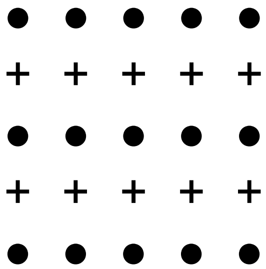


Gestalt law of proximity

Fig. 9 (Anderson, 1996, p. 43)

Spatial or temporal proximity leads to a perception of a collective or totality. Elements that are closer together will be perceived as a coherent object.

We rather perceive four pairs of lines than eight single lines.



Gestalt law of similarity

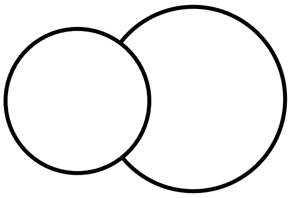
Fig. 10 (Anderson, 1996, p. 43)

Similar elements are perceived as being part of the same form. The similarity might depend on relationships of form, colour, size, or brightness.

We are prone to perceive the pattern as rows of circles which alter with rows of crosses. Similar objects are grouped together.

---

[9] Funded by the German ministry for research (BMBF) and co-ordinated by the German machine tool builder association VDW

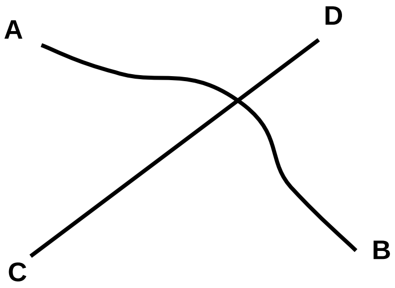


Gestalt law of good form

Fig. 11 (Anderson, 1996, p. 43)

A stimulus will be organised into a figure as well as possible. Here, “good” means symmetrical, simple, and regular.

The figure appears to the eye as two overlapping circles, not a combination of several complicated shapes.

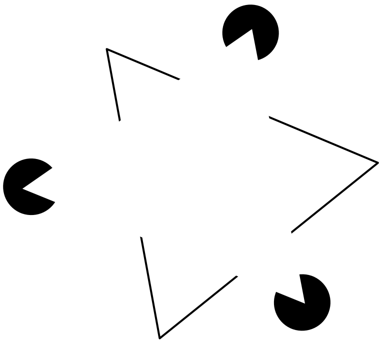


Gestalt law of continuity

Fig. 12 (Anderson, 1996, p. 43)

Human perception completes visual patterns. There is a tendency to continue contours whenever the elements of the pattern establish an implied direction.

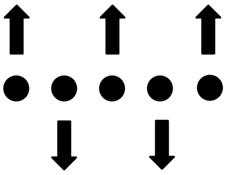
In the example, people tend to draw a good continuous line.



Gestalt law of closure

Fig. 13 (Matlin & Foley, 1997, p. 152)

We tend to enclose a space by completing a contour and ignoring gaps. We may experience elements we do not perceive through sensation, which lead to the perception of a regular figure.



Gestalt law of common fate

Fig. 14 (Matlin & Foley, 1997, p. 130)

When objects move in the same direction, we tend to see them as a unit.

In the example, when the dots 1, 3, and 5 move upwards and dots 2 and 4 move downwards at the same time, the dots moving in the same direction are perceived as a group

4.2 Usability engineering

Usability engineering applies standards, empirical methods and operational definitions of user requirements in the design and evaluation of products. Use of the resulting products should as intuitive as possible; taking the minimum of time to learn their operation and to accomplish the desired task. McLaughlin (1987) concludes: “*The main consideration is reducing the likelihood that the end user will not or cannot effectively use the system. The process begins with user analysis to produce cognitive and work style models, and task analysis to produce user work functions and scenarios. Feedback is rapid and productive, and user effectiveness can be measured and observed before the system is built and fielded*” (p. 183).

By integrating the user in the design process, it is possible to identify any “*… significant gap[s] between the use situation as envisaged by the designer and that which actually exists in practice*.” (Hale, Kirwan and Kjellén, 2007, p. 314). According to Wilpert (2007), the existence of such ‘perception gaps’ can be explained by designers’ tendency to overestimate users’ technical know-how.

A user-centred design should result in greater satisfaction on the part of the operator and reduce development costs (Urbas, Steffens, Beu & Jacob, 2005). However, despite the competitive advantage offered by usability engineering, it is still widely ignored in industry. In most instances, it is still technical feasibility that dictates the division of functions between human beings and machine, with the user only being involved in the final testing phase. Frequently, difficulties in learning how to operate a machine or common operating errors are only identified at this late stage, by which time it is often too late to make the necessary changes.

There are a number of questions which should be addressed at the start of the design process:

- Is the information presented in a way that is adequate to the task?
- Can the design be understood intuitively?
- Is the HMI equal to the expectations of the operator?
- How error tolerant is the system?
- Can the HMI be adapted to several user groups?
- Does the HMI support learning how to run the system?

The usability engineering process can be separated into four iterative phases: (1) analysis phase (concerning working system, work, target groups, identification of user demands), (2) concept phase (concept of use with respect to different user target groups and decision on system functionality), (3) development phase (development of prototype and system integration), (4) implementation phase (pilot installation of prototype, industrial engineering).

Users are involved in all stages and take an active part in the evaluation processes under the moderation of usability engineers. The integration of operators in the design process right from the start avoids iterative loops which commonly occur when the testing of HMI is left until the final stages of the process. Involvement of operators in the evaluation process can be achieved through the use of surveys; by direct observation of the user at his workplace; through structured discussions; by participation of the user in design workshops; or through feedback concerning prototypes or products in usability tests. (Koller, Beu & Burmester, 2004 in Luczak, Schmidt, Koller).

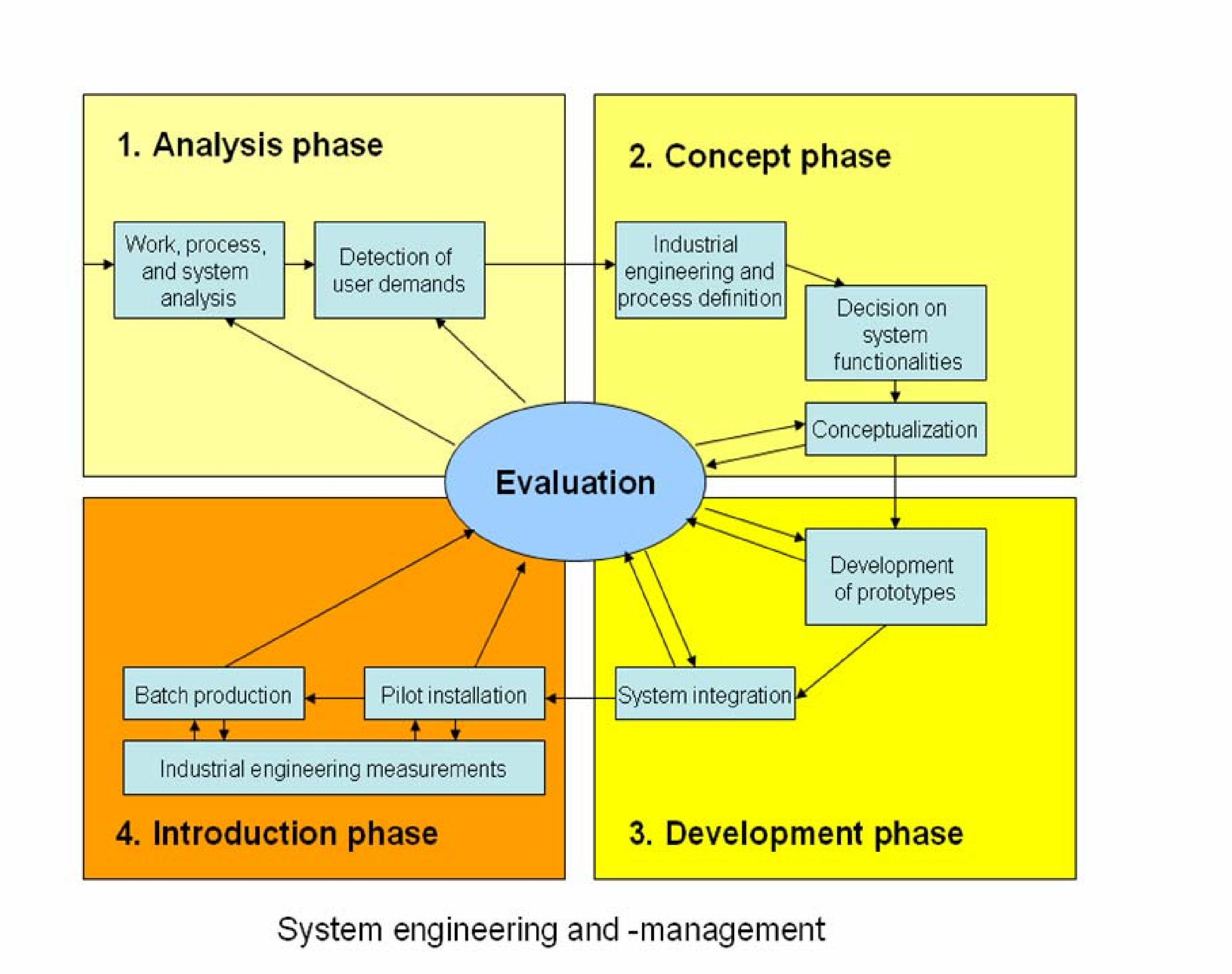


Fig. 15: Process model “Usability Engineering” (Sarodnick & Brau, 2006, p. 85), Copyright by Hogrefe, Verlag Hans Huber Bern 2008

Analysis phase:

It is important to ensure that the interface is properly adapted to the task and to the conditions in which the task will be performed. During the analysis phase, the following types of questions must be addressed: Which tasks occur and how often? How are the tasks managed? Who performs them? In what time do they need to be accomplished? What skills are necessary? How are the tasks linked together? What qualifications and qualities do the people performing the tasks have? How do they work together? What hardware and software do they use? What are the working conditions? It is essential to gather information on requirements directly from the operators as they are experts in their work and their ideas may well prevent less than optimal developments (Sarodnick & Brau, 2006).

Concept phase:

Based on the results of the analysis phase, an interdisciplinary team made up of usability experts, industrial engineers, designers and experts involved in organisational development create a concept for the design of the HMI. This phase must consider, for example whether the technical innovations will lead to changes in the existing working process. An important step is the allocation of tasks to humans and to machines, which implies an assessment of the functionalities within the system. The concept must be evaluated and the new system may be adapted (Sarodnick & Brau, 2006).

Development phase:

Development involves constructing a prototype and evaluating it. This phase gives importance not only to functionality, but also to aesthetic design. Designs of HMI should not only be usable but also permit “joy of use” (Sarodnick & Brau, 2006).

Implementation phase:

The implementation of the HMI is first of all carried out within a limited set of users and should involve evaluation measures. If amendments are necessary, a loop back to the development phase should follow. If the implementation is judged to be successful, the implementation can be enlarged, but should be accompanied by further evaluation measures. During the whole implementation process, any worries or fears expressed by users should be taken into account so as to help avoid acceptance problems (Sarodnick & Brau, 2006).

4.3 Virtual Reality

Innovations that support users in their interactions with machines offer gains not only in efficiency and productivity, but also in users’ performance and in reduction of health and safety risks. Virtual reality (VR) technology makes it possible to enrich the real (working) context with computer-simulated environments or objects to different degrees. At one end of the spectrum, VR depicts a world that is entirely computer-generated, which the user perceives as such and can interact with in real time. At the other end, “augmented reality” enriches the real world with computer-generated information. In between the two is “Mixed reality”, which describes the whole continuum between the real world and the virtual world. (Schmidt, Wiedenmaier, Oehme, Luczak, 2004 in Luczak, Schmidt, Koller).

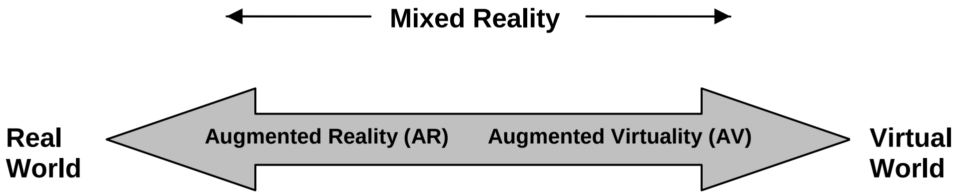


Fig. 16: ‘Virtuality Continuum’ (VC) according to Milgram, Takemura, Utsumi and Kishino (1994)

Invented in the 1960s, VR-technology began to be applied in industry in the mid 1990s and is now applied in many fields e.g. medicine, engineering, industry, architecture, research and education. Its uses include design conception, practical training, maintenance and better understanding of occupational accidents (Ciccotelli & Marsot, 2005).

VR is characterised by two essential aspects: the fact that users not only perceive a computer-generated world, but that they also interact in this world in real time. Below are some examples of how VR can improve health and safety when it is applied to HMI:

- Ciccotelli and Marsot (2005) mention that iterative design processes can be simplified by using VR simulations to conduct user tests, thereby reducing or eliminating altogether the need for extensive, time-consuming prototypes.
- Määttä (2003) applied VR technology to machinery safety analysis by combining a virtual environment with a 'participative ergonomics approach', work safety analysis methods and task analysis methods. Määttä used this approach to analyse hazards during modernisation projects in different plants (e.g. hot steel storage plant, steel converter plant) and demonstrated the usefulness of VR technology in safety analysis.
- Weiner (2007) describes a virtual safety training program for excavator drivers, which allows them to undertake practical exercises in realistic conditions, but without the real-world safety risks. The training takes place in a reproduction of an excavator driver's cab, using VR glasses to generate a virtual landscape while drivers use steering-wheel, accelerator, and brake pedal to operate the virtual excavator. Different tasks have to be accomplished, such as driving in areas without obstacles, driving on slopes, driving around obstacles, driving in different weather conditions and on different terrain.
- VR is also frequently used to train nuclear power plant staff, e.g. reactor operators, allowing them to experience realistic simulations of critical situations (Markidis & Rizwan, 2006).

There are still technological limits in creating high-fidelity VR images, especially concerning multimodal interaction beyond visual and auditory interaction. Nevertheless, VR technology is an area of HMI that is evolving rapidly and has the potential to be of great relevance to OSH.

4.4 Augmented Reality (AR)

Augmented reality (AR) describes an environment that includes both virtual and real-world elements. The user's field of vision is enriched with computer-generated virtual objects in order to make additional product or process information available in the context of the perceived reality (Schmidt, Wiedenmaier, Oehme, and Luczak, 2004 in Luczak, Schmidt, and Koller). Typically, goggles or screens are used to superimpose computer-generated information and images on the view of the real world. Unlike VR, AR allows the user to interact with real-world subjects and objects and is less likely to give false tactile or proprioceptive feedback.

Azuma (1997) identified the following areas of application for AR: medicine, manufacturing and repair, annotation and visualisation, robot path planning, entertainment, and military aircraft. Schmidt, Wiedenmaier, Oehme, and Luczak (2004 in Luczak, Schmidt, Koller) mention that AR is also used in areas such as simulation of real estate in architecture or enrichment of the interior design with virtual objects and in development, production and service (for instance maintenance).

Sakas (2002) described the uses of AR in medicine, such as combined with computer tomography, for training systems, in 3D angiography and in 3D ultrasound. He noted that with increasing computer power and falling prices, this technology has become widespread in medicine today.

(Ong, Yuan and Nee, 2007) describe the uses of AR in simulating and improving the design of manufacturing processes.

Head-up displays for civilian pilots have been shown by Bandow (2006) to reduce stress, particularly during abnormal flight situations and the final approach, and also to improve situational awareness.

AR can facilitate tasks such as maintenance or assembly by projecting operating instructions, labels of system parts, or construction plans on top of the view of the real system.

The application of AR-systems depends on the context, such that additional information provided by AR is adapted to the job. The aim is to provide the user with as much support as possible, while ensuring that the operation of AR-system itself demands minimal attention.

An example of the type of user support that can be provided by AR is the context navigator developed by the ARVIKA human-technique-interaction project supported by the German Federal Ministry for Education and Research. "Context objects" are detected, such as the position of the user, his line of vision, his working processes, tasks accomplished and those yet to be undertaken. Based on this information, the context manager provides the user with data relevant to the task and situation. The user can select which of the context objects to view in the mobile AR-system. A service technician, for example, could view layout plans or pipe plans for the job in hand. (Quaet-Faslem, Womann & Beu, 2004 in Luczak, Schmidt, Koller).

4.5 Instruction manuals

Correct installation and operation of technological products is critical for health and safety. In practice, however, many accidents are caused by faulty installation or operation as a consequence of either not reading or failing to understand the relevant instructions (You, Young, Zimmermann, Ekrut, Kumar & Lee, 2001; Wiese, Sauer & Rüttinger, 2004). The importance of providing adequate instructions is reflected in the provisions of the machinery Directive 98/37/EC and ISO standards relating to technical product documentation

Reinert, Brun & Flaspöler (2007) identified success factors in communicating safety-related information as part of a project to make more users read and understand operating instructions. The study “Complex machinery needs simple explanation” concluded that the best concept for presenting safety-related information consists of a multimedia package for operating instructions comprising a video and poster as well as a paper version of the operating instructions.

A video gives elementary information and can raise users’ awareness at the outset using appropriate animation. Posters are able to explain the key information at a glance and can be placed where the work is being carried out. The main aim of the poster and video is to encourage users to extend their knowledge by referring to the written operating instructions. Several measures were identified that ensure that the information is communicated as effectively as possible:

- Visual aids providing an overview of the most important information can integrate simulations, illustrations, comics, photos, tables, coloured text, etc.
- The text must be readable. It should be simple, with logical sentences using the active rather than passive form and structured in short informative chapters.
- Contents tables and indexes allow the user to find specific information at a glance.
- Checklists make text more user-friendly and help guide the users through the necessary steps and let them see whether they have worked adequately.
- Instructions for correct operation should be presented sentence by sentence and warnings should be emphasised in the text.
- Symbols, terminology and units of measurement should be used consistently (as defined in available standards) and tables should describe them further. Formulae and concepts should be explained. Glossaries should be used to explain key terminology.
- Special attention must be paid to ensure that translations into other languages are adequate. The use of cartoons assists understanding for all readers.
- Software help functions and interactive features enable the user to work efficiently with the system.
- Quizzes, cross-words, or other games may be used to evaluate the user’ knowledge.

Similar success criteria can be found in standards and should be fulfilled when designing operating instructions for products or machines. In practice, however, many examples of operating instructions fail to meet even the minimum requirements specified in the norms.

5 Standards relating to HMI

5.1 The role of standards in HMI design

Standards play an important part in the application of design principles, but their application is also limited. Firstly, the pace at which technology develops means that legislation, standards and guidelines are always lagging behind to some extent. Secondly, awareness concerning standards and guidelines relevant to HMI is relatively low. This may be due to the tremendous amount of information given in standards, which may be seen as too much of a challenge for many – especially smaller - enterprises.

A number of standards are relevant to HMI and they are described below. International standards ISO 9241[10] and ISO 13407[11] cover work with computers and other interactive systems and serve to illustrate the multidisciplinary approach that is needed to ensure effective HMI. These standards combine knowledge from the fields of software engineering, work science and cognitive ergonomics.

ISO 9241 deals with various aspects of human computer interaction (HCI). Originally entitled "Ergonomic requirements for office work with visual display terminals (VDTs)", its field of application has been extended and it is now called "Ergonomics of Human System Interaction".

Following the general introduction in Part 1 of ISO 9241, Part 2 provides guidance on task requirements and task design for working with computer systems; Parts 3–9 deal with physical characteristics of computer equipment like visual display requirements, keyboard requirements or workstation layout and postural requirements; and Parts 11 to 19 and 110 deal with usability aspects of interactive systems. Part 110 is of particular relevance to HMI in that it specifies general ergonomic design principles without reference to particular situations of use or applications. Intended to serve as a general framework for the analysis, design and evaluation of interactive systems, it is based on seven general principles that apply to the interaction of people and information systems:

1. Suitability for the task – the dialogue or the product should be suitable for the user's particular task and specific skill level.
2. Self-descriptiveness – the dialogue should be transparent at any step in the interaction.
3. Controllability – the user should be able to control the steps and the speed of the interaction.
4. Conformity with user expectations - the dialogue should be consistent with the user's intuition or expertise.
5. Error tolerance - the dialogue should anticipate user actions and compensate or "forgive" possible mistakes by the user.
6. Suitability for individualisation – the dialogue should be able to be customised to suit the individual user or specific groups of users.
7. Suitability for learning – the dialogue should support or ease its learning.

These principles are often used as the basis for evaluation of interactive systems. Furthermore, ISO 9241 (part 11) provides a widely used definition of usability: "*The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.*"

Whereas ISO 9241 covers ergonomic requirements, ISO 13407 deals with the design process of interactive systems. In providing guidance for the complete life cycle of a product, it gives reasons for the application of a human-centred design process; provides references to relevant standards; and advises on planning and management.

Depending on the context, there are a great number of standards that are also relevant to HMI. Nachreiner et al. (2006), for example, refer to standards relevant to the design of process control systems, which include EN 641-1[12] and ISO 11064:5[13].

---

[10] ISO 9241:1998 Ergonomic requirements for office work with visual display terminals (VDTs)

[11] ISO 13407:1999 Human-centred design processes for interactive systems

[12] EN 614-1:2006 Safety of machinery. Ergonomic design principles. Terminology and general principles

[13] ISO 11064-5:2008 Ergonomic design of control centres -- Part 5: Displays and controls

5.2 Overview of European and international standards relating to HMI[14]

EN standards are ratified by one of the three major European committees for standardisation (Comité Européen de Normalisation/European Committee for Standardisation (CEN)); Comité Européen de Normalisation Electrotechnique/European Committee for Electrotechnical Standardisation (CENELEC) or European Telecommunications Standards Institute (ETSI)).

EN ISO standards are developed by one of the three major European committees for standardisation listed above and the International Organisation for Standardisation (ISO).

ISO standards are ratified by the International Organisation for Standardisation (ISO) which is composed of national standards bodies from over 75 countries.

ISO/IEC standards are worked out by a joint committee of the International Organisation for Standardisation (ISO) and the International Electrotechnical Commission (IEC) (JTC1).

IEC standards are developed by the International Electrotechnical Commission (IEC).

Abbreviation	Name	Parts
EN standards ratified by CEN, CENELEC, or ETSI:		
EN 349	Safety of machinery; minimum gaps to avoid crushing of parts of the human body	
EN 547	Safety of machinery – Human body measurements	Part 1: Principles for determining the dimensions required for openings for whole body access into machinery Part 2: Principles for determining the dimensions required for access openings Part 3: Anthropometric data
EN 614	Safety of machinery – Ergonomic design principles	Part 1: Terminology and general principles Part 2: Interactions between the design of machinery and work tasks
EN 894	Safety of machinery – Ergonomic requirements for the design of displays and control actuators	Part 1: General principles for human interactions with displays and control actuators Part 2: Displays Part 3: Control actuators Part 4: Location and arrangement of displays and control actuators
EN 1005	Safety of machinery – Human physical performance	Part 1: Terms and definitions Part 2: Manual handling of machinery and component parts of machinery Part 3: Recommended force limits for machinery operation Part 4: Evaluation of working postures and movements in relation to machinery Part 5: Risk assessment for repetitive handling at high frequency
EN 13861	Safety of machinery – Guidance for the application of ergonomics standards in the design of machinery	
EN 60447	Basic and safety principles for man-	

---

[14] The following list of standards related to HMI was compiled using Perinorm, the leading bibliographic database of national, European and international standards. Complementary information was taken from the standards publication house Beuth Verlag and sources such as Usability Net.

	machine interface, marking and identification – Actuating principles	
EN ISO standards are developed by the by CEN, CENELEC, or ETSI and the International Organisation for Standardisation (ISO)		
EN ISO 6385	Ergonomic principles in the design of work systems	
EN ISO 9241 (EN ISO 9241-117 is intended to revise and replace ISO 16071. EN ISO 9241-10 is revised by EN ISO 9241-110)	Ergonomics of human-system interaction (earlier called: Ergonomic requirements for office work with visual display terminals (VDTs))	Part 1: General introduction Part 2: Guidance on task requirements Part 3: Visual display requirements Part 4: Keyboard requirements for visual display terminals Part 5: Workstation layout and postural requirements Part 6: Guidance on the work environment Part 7: Requirements for display with reflections Part 8: Requirements for displayed colours Part 9: Requirements for non-keyboard input devices Part 11: Guidance on usability Part 12: Presentation of information Part 13: User guidance Part 14: Menu dialogues Part 15: Command dialogues Part 16: Direct manipulation dialogues Part 17: Form filling dialogues Part 110: Dialogue principles Part 117: Guidance on software accessibility
EN ISO 10075	Ergonomic principles related to mental workload	Part 1: General terms and definitions Part 2: Design principles Part 3: Principles and methods for measuring and assessing mental workload
EN ISO 11064	Ergonomic design of control centres	Part 1: Principles for the design of control centres Part 2: Principles for the arrangement of control suites Part 3: Control room layout Part 4: Layout and dimensions of workstations Part 5: Displays and controls Part 6: Environmental requirements for control centres Part 7: Principles for the evaluation of control centres
EN ISO 12100	Safety of machinery – Basic concepts, general principles for design	Part 1: Basic terminology, methodology Part 2: Technical principles
EN ISO 13406	Ergonomic requirements for work with visual display based on flat panels	Part 1: Introduction Part 2: Ergonomic requirements for flat panel displays

EN ISO 13407	Human-centred design processes for interactive systems	
EN ISO 14738	Safety of machinery – Anthropometric requirements for the design of workstations at machinery	
EN ISO 14915	Software ergonomics for multimedia user interfaces	Part 1: Design principles and framework Part 2: Multimedia navigation and control Part 3: Media selection and combination
ISO standards ratified by the International Organisation for Standardisation (ISO)		
ISO 16071 (The standard will be replaced by ISO 9241-171)	Guidance on accessibility for human-computer interfaces	
ISO 16982	Ergonomics of human-system interaction – Usability methods supporting human-centred design	
ISO 18529	Ergonomics of human-system interaction – Human-centred lifecycle process descriptions	
ISO 20282		Part 1: Design requirements for context of use and user characteristics
ISO 9127		
ISO/IEC standards developed by a joint committee of ISO and IEC (JTC1):		
ISO/IEC 9126	Software engineering – Product quality	Part 1: Quality model Part 2: External metrics Part 3: Internal metrics Part 4: Quality in use of metrics
ISO/IEC 10741	Information technology – User system interfaces	Part 1: Cursor control for text editing
ISO/IEC 11581	Information technology - User system interfaces and symbols - Icon symbols and functions	Part 1: Icons – General Part 2: Object icons Part 3: Pointer icons Part 5: Tool icons Part 6: Action icons
ISO/IEC 14598	Information technology – Software product evaluation	Part 1: General overview Part 2: Planning and management Part 3: Process for developers Part 4: Process for acquirers Part 5: Process for evaluators Part 6: Documentation of evaluation modules
ISO/IEC 14754	Information technology – Pen-based interfaces – Common gestures for text editing with pen-based systems	
ISO/IEC 15504		Improvement and process capability determination

ISO/IEC 15910	Information technology – Software user documentation process	
ISO/IEC 18019	Software and system engineering – Guidelines for the design and preparation of user documentation for application software	
ISO/IEC 18021	Information technology – User interfaces for mobile tools for management of database communications in a client-server model	
IEC standards developed by the IEC		
IEC 61997	Guidelines for the user interface in multimedia equipment for general purpose use	

Technical Reports (ISO TR) by the International Organisation for Standardisation can be regarded as informative documents containing information which is different from information given in normative standards. Technical Specifications (ISO TS) of the International Organisation for Standardisation are normative documents that may later be revised and published as a standard.

5.3 Directives

Two European directives of particular relevance to usability – the display screen directive and the machinery directive – have been implemented through national legislation in each Member States.

Abbreviation	Name	Contents
Directive 90/270/EEC	Display Screen Equipment Directive	Minimum ergonomic requirements for workstation equipment and the environment / Principles of software ergonomics
Directive 98/37/ EC	Machinery Directive	Health and safety requirements for machinery (e.g. user-friendly interactive software)

6 Conclusion

As science and technology advance, we find increasingly complex machines, as well as an evermore widespread automation in the workplace. The HMI governs the flow of information from the machine to the user (in terms of displays, warning sounds, etc.) and from the user to the machine (in terms of input or control devices such as keyboards, switches, levers, etc.). Its design has important consequences for health and safety at work because of the growing potential for accidents and ill health for machine operators. Increasing complexity affects not only the way operators use a machine, but also leads to more automation, which in turn impacts on the way work is organised.

The majority of machine users work in SMEs; mostly in manufacturing, although significant numbers also work with machines in construction, communication and transport, and agriculture. No age group is more or less likely to work with machines, but users typically have lower than average skill level and work full time. Compared with the general working population, machine workers are more likely to carry out repetitive work, to work standing upright and to carry heavy loads. As might be expected, they are also more exposed to poor environmental conditions such as fumes and dust, heat or cold, noise and dangerous substances and are more likely to have to wear personal protective equipment. Finally, machine workers have significantly less control over their work organisation, breaks or amount of work than other workers.

Deficiencies in the HMI present both a psychosocial risk and an accident risk. In the first case, stress can result from cognitive overload or under-load and in the second, occupational accidents can result from operating errors. Additionally, human error can also result in major accidents; typically in high-risk industries, such as nuclear, oil, gas, etc.

A machine user can suffer cognitive overload if, for example, too much information is given too quickly, or it is not readily understandable, or it is ambiguous, or conflicts with other information or is unexpected. Cognitive under-load, in contrast, tends to arise where automation has taken the content out of a person’s job so that it lacks interest and is not stimulating. An example might be monitoring of a highly automated manufacturing process.

Poor HMI can lead to occupational accidents in a number of ways. The most common cause is an operational error arising out of, for example, failure to understand or to act upon the information provided by the machine, or inability to control the machine correctly, for example because of an input error. Many accidents, however, can also be attributed to the HMI not being adapted to non-routine operation, such as during maintenance or repair. Finally, a badly designed HMI can also encourage inappropriate actions, such as taking shortcuts or making modifications to the machine, such as bypassing safety devices, which often lead to accidents.

The main impact of widespread computerisation is the possibility of providing the operator with very high levels of information and functionality. In many cases, however, designers are not aware of the relevant design principles and tend to overload the user, who then finds it difficult to interpret information and control the machine. A further consequence of this tendency is the need for longer training and more detailed instructions.

New technology, when introduced poorly, carries the risk of increasing operators’ mental workload and also of reducing their degree of task control. Furthermore, the resulting changes in work organisation demand a holistic, systems-based approach that optimises allocation of tasks and the working environment in order to reach an ergonomic workplace design. Also essential to this approach is the provision of proper information and training and the involvement of workers in the change. A failure to take these measures increases the risk of have negative health effects such as stress and is likely to result in an over-reliance on automated safety systems.

It must be borne in mind that technology offers the potential to substantially improve HMI by, for example, providing better information and feedback or by facilitating control. However, in order to realise the potential, the design principles described in this report need to be applied. It is generally agreed that the potential offered by new technology is realised only to a small extent. Some differences, however, exist between various branches of industry, depending on their familiarity with complex HMI.

The largest scope for improvement is in the consideration of workers and their needs in the design process. The focus on the human factor needs to be increased to take account of physical aspects (such as perceptual processes) and psychological aspects (such as cognitive processes). The design process should serve to reinforce human factor potentials and limitations. Input from users to the design process is essential and can be based on testing (e.g. using prototypes or mock-ups) or on the experience of existing users of similar technology (if available).

Moreover, achievement of a good HMI does not end with an adequate design. The implementation of the new technology and its combination with existing machines and installations at the workplace is a vital, if often overlooked, step. Typically, operationalisation is too late, too little, or does not happen at all. Correct operationalisation is also important when technology is transferred from one sector to another or when integrating and adapting complex automated processes to the business context or to another cultural background.

An important obstacle to the fulfilment of technology's potential to improve HMI is the pace of development and pressure to deliver technical solutions quickly, which limits the time available for design and testing.

Workers often encounter difficulties adapting to technological change, particularly if it is done quickly. Therefore, it is important to implement changes to machines, technologies, or processes in a step-wise manner, so as to avoid overloading workers. Resistance to change can also come from the enterprise itself; possible because of a perception that the benefits of the new technology do not justify the costs of purchase and installation. Off-the-shelf production can be of poor fit, but customised production is expensive and probably not so reliable, as there can be compatibility problems between items of equipment and systems. The engineering of machine controls is often outsourced with the result that development of HMI is given less importance. The cost of testing also means that usability is often evaluated only to the extent of ensuring there are no potentially dangerous features.

Last but not least, standards and guidelines provide an important framework covering design of HMI, aspects of the design process and accompanying material, such as user instructions. Unfortunately, the applications of standards and guidelines low in practice and their relevance is sometimes limited by the pace of technical development.

6.1 Recommendations for research

There is still much basic research that needs to be carried out and the results of existing research need to be put into practice more effectively. The following non-prioritised list identifies some of the most important priorities for HMI-related research:

- Field studies are needed so that organisational and environmental factors that are difficult to replicate under laboratory conditions can be properly taken into account.
- Accident investigation data needs to be improved and harmonised so as to enable better analysis and identification of causation.
- Usability testing should include evaluation of HMI under emergency situations, rather than just normal operation, as operators' actions can be very different in these circumstances.
- More research is needed that focuses on the needs of specific worker groups:
    - New technology can facilitate access to the labour market for disabled workers
    - More account needs to be taken of maintenance workers, such as ensuring that menu navigations specific to maintenance work are always included and are of high quality.
    - Migrant workers are more likely to have difficulties in understanding instructions, written commands, etc. and may have different expectations and levels of experience.
- Jobs involving complex tasks and time pressure need further investigation as part of a greater research effort into cognitive ergonomics, work motivation and well-being at work.
- Research into the importance of user-friendliness is needed to avoid systems becoming 'black boxes', with operators not understanding how they work.
- Cost-benefit analyses need to demonstrate the cost effectiveness of ensuring an optimal HMI as regards increased productivity and decreased implementation costs.
- Findings from different studies need to be combined to a greater extent and collaboration must increase between groups such as developers, users and suppliers.
- Research needs to be put into practice more effectively.

References

Anderson, J. R. (1996). Kognitive Psychologie. Spektrum Akademischer Verlag: Heidelberg.

Azuma, R. (1997). A survey of augmented reality. Presence: Teleoperators and Virtual Environments, 6 (4), 355-385.

Backström, T. & Döös, M.: The technical genesis of machine failures leading to occupational accidents. International Journal of Industrial Ergonomics, Vol. 19(5), pp. 361-376, 1997.

Backström, T. & Harms-Ringdahl, L.: A statistical study of control systems and accidents at work. Journal of Occupational Accidents, Vol. 6, pp. 201-210, 1984.

Backström, T., Döös, M.: A comparative study of occupational accidents in industries with advanced manufacturing technology. International Journal of Human Factors in Manufacturing, Vol. 5 (3), pp. 267-282, 1995

Bainbridge, L.: Ironies of Automation. In Rasmussen, J., Duncan, K., Leplat, J. (Hrsg.): New Technology and Human Error. N.Y.: Wiley 1987.

Bandow, D. (2006). Head-up-Guidance-Systeme und Mensch-Maschine-Interaktion. Zeitschrift für Arbeitswissenschaft 60 (2), 107-121.

Baumann, K. & Lanz, H.: Mensch-Maschine-Schnittstellen elektronischer Geräte. Leitfaden für Design und Schaltungstechnik. Berlin-Heidelberg: Springer, 1998.

Becker, F. Leistungsfähige Systembausteine zur Erfüllung der Kommunikationsanforderungen. Glückauf, Nr. 11, Essen: VGE-Verlag GmbH, 2006.

Beer, B.: Gestaltung der Schnittstelle Mensch/Anlage/Prozess im Rahmen von Anlagenplanungen-Sicherheitsbezogene Anforderungen und Untersuchungsergebnisse. Zeitschrift für Arbeitswissenschaft, 55 (4), pp. 214-215, 2001.

Bubb, H.: Menschliche Zuverlässigkeit, Sicherheit und Risikobeurteilung. Zeitschrift für Arbeitswissenschaft, Köln (20NF), S. 8-13, 1994.

Bundesministerium für Wirtschaft und Arbeit (2001). Arbeitsunfälle mit Maschinen, Studie der Arbeitsinspektion. Wien. http://www.arbeitsinspektion.gv.at/NR/rdonlyres/6F647B66-AAD9-4263-93B7-A73AD215A1BF/0/masch_unfaelle.pdf

Carey, J.M.: Human factors in management in formation systems. Ablex Publishing Corporation: Norwood, New Jersey, 1998.

Charwat, J.: Lexikon der Mensch-Maschine-Kommunikation. München, Wien: Oldenbourg, 1992.

Ciccotelli, J. & Marsot, J. Réalité virtuelle et prévention. Apports et tendances. Hygiène et sécurité du travail – Cahiers de notes documentaires, 199, Points de repère – PR 17, 99-111, 2005.

Dahm, M.: Grundlagen der Mensch-Computer-Interaktion. Pearson Studium: München, 2006.

Ditchen, D., Ellegast, R.P., Herda, C., Hoehne-Hückstädt, U. Ergonomic intervention on musculoskeletal discomfort among crane operators at waste-to-energy-plants Contemporary Ergonomics 2005. S. 22-26, 5 Lit., 1 Tab., 3 Abb. Hrsg.: Bust, P.D.; McCabe, P.T. Taylor & Francis, London.

Döös, M. & Backström, T.: Production disturbances as an accident risk. In Kidd, P.T. & Karwowski, W. (Eds.): Advances in agile manufacturing. pp. 375-378. IOS Press, London 1994.

Döös, M., Backström, T. & Samuelsson, S.: Evaluation of a strategy. Preventing accidents with automated machinery through targeted and comprehensive investigations conducted by safety engineers. Safety Science, Vol. 17(3), pp. 187-206, 1994.

Döös, M., Backström, T. & Sundström-Frisk, C.: Human actions and errors in risk handling - an empirically grounded discussion of cognitive action-regulation levels. Safety Science, vol 42, pp. 185-204, 2004.

Dreher, K.: Der 12-Punkte Plan: HMI maßgeschneidert. Computer Automation, 10, 48-53, 2001.

Einarsson, S. (1999). Human error in high hazard systems: Do we treat the problem in an appropriate way? Journal of Risk Research, 2:2, 115-128.

Ellegast, R.P., Lesser, W., Herda, C., Hoehne-Hückstädt, U., Schwan, W. & Kraus, G. Physical workload at sewing workplaces - an ergonomic intervention study (IEA 2006. 16. World Congress on Ergonomics. 10.-14. Juli 2006, Maastricht/Niederlande - Vortrag. CD-ROM, 6 S., 10 Lit., 4 Tab., 3 Abb. Hrsg.: Pikaar, R.N.; Koningsveld, E.A.P.; Settels, P.J.M. Elsevier Ltd. 2006

EU-OSHA: Priorities for occupational safety and health research in the EU-25. Luxembourg: Office for Official Publications of the European Communities, 2005.

EU-OSHA: Expert forecast on emerging physical risks related to occupational safety and health. Luxembourg: Office for Official Publications of the European Communities, 2005.

Gerr F, Marcus M, Ensor C, Kleinbaum D, Cohen S, Edwards A, Gentry E, Ortiz DJ, Monteilh C. 2002. A Prospective Study of Computer Users: I. Study Design and Incidence of Musculoskeletal Symptoms and Disorders. Am J Ind Med 41(4):221-35.

Hale, A., Kirwan, B. & Kjellén, U. (2007). Safe by design: where are we now? Safety Science, 45, 305-327.

Haller, L.: Risikowahrnehmung und Risikoeinschätzung. Schriften zur Arbeits-, Betriebs- und Organisationspsychologie. Volume 3. Verlag Dr. Kovač. 2003.

Hoehne-Hückstädt, U.; Keller Chandra, S.; Ellegast, R.P.; Schäfer, P. Ergonomic requirements on input devices of information technology (Ergonomische Anforderungen an Eingabemittel der Informationstechnik) Contemporary Ergonomics 2007. S. 415-420, 22 Lit., 1 Tab. Hrsg.: Bust, P.D. Taylor & Francis, London. ISBN: 13 978-0-415-43638-0 (Sprache:GB)

Hollnagel, E.: Cognitive Reliability and Error Analysis Method (CREAM). Oxford: Elsevier Science Ltd. 1998.

HVBG (2006). Manipulation von Schutzeinrichtungen an Maschinen. Hauptverband der gewerblichen Berufsgenossenschaften. Sankt Augustin http://www.dguv.de/bgia/de/pub/rep/pdf/rep05/manipulation_schutzeinrichtungen/vorspann.pdf

Ipsos-MORI (1999) Employees Get 'It' Out Of Their Systems http://www.ipsos-mori.com/researchpublications/researcharchive/poll.aspx?oItemId=1900

Koller, F., Beu, A. & Burmester, M.: Benutzerzentrierter Gestaltungsprozess interaktiver Systeme. In Luczak, H., Schmidt, L. & Koller, F.: Benutzerzentrierte Gestaltung von Augmented Reality. pp. 15-26. VDI Verlag. Düsseldorf, 2004.

Määttä, T. (2003). Virtual environments in machinery safety analysis. VTT publications 516, Finland. http://www.vtt.fi/inf/pdf/publications/2003/P516.pdf

Marcus, M. & Gerr, F. (1996). Upper extremity musculoskeletal symptoms among female office workers: Associations with video display terminal use and occupational psychosocial stressors. American Journal of Industrial Medicine, 29(2), 161-170.

Markidis, S. & Rizwan, U. A virtual control room with an embedded, interactive nuclear reactor simulator. 5th International Topical Meeting on Nuclear Plant Instrumentation Controls, and Human-machine Interface Technology (NPIC and HMIT 2006), vol. 2006, 675-679.

Matlin, M. W. & Foley, H. J. (1997). Sensation and Perception. Allyn & Bacon: Old Tappan, NJ.

Mattila, M. & Kiviniitty, J.: Job characteristics and occupational safety of manufacturing jobs at different levels of automation. International Journal of Human Factors in Manufacturing, Vol. 3 (3), pp. 243-252, 1993.

Mattila, M., Tallberg, T., Vannas, V. & Kivistö-Rahnasto, J.: Fatalities at advanced machines and dangerous incidents at FMS implementations. International Journal of Human Factors in Manufacturing, Vol. 5 (3), pp. 237-250, 1995.

McLaughlin, L. L.: User engineering: a new look at system engineering. First Annual Workshop on Space Operations Automation and Robotics (SOAR '87)., Houston, TX, NASA Conference Publication, n 2491, pp. 183-189, 1987.

Milgram, Paul; H. Takemura, A. Utsumi, F. Kishino (1994). "Augmented Reality: A class of displays on the reality-virtuality continuum" (pdf). Proceedings of Telemanipulator and Telepresence Technologies: 2351-34.

Miller, D. & Swain, A.: Human Error and Human Reliability. In Salvendy, G. (Hrsg.): Handbook of Human Factors and Ergonomics. N. Y.: Wiley, 1986.

Montenegro, S.: Sichere und fehlertolerante Steuerungen. Entwicklung sicherheitsrelevanter Systeme. Hanser. München, Wien, 1999.

Nachreiner, F., Nickel P and Meyer I. (2006). Human factors in process control systems: The design of human–machine interfaces. Safety Science, vol. 44, 2006, 5-26.

Oberhuber, N. Mensch gegen Maschine, DIE ZEIT 16.09.2004 Nr.39 http://images.zeit.de/text/2004/39/Computerfrust

Ong S. K., Yuan M. L. & Nee, A. Y. C. (2007). Augmented reality applications in manufacturing: a survey. International Journal of Production Research, 1-36.

Park, S. P.: Human Error. In G. Slavendy (Hrsg.): Handbook of Human Factors and Ergonomics. N. Y.: Wiley, 1997.

Quaet-Faslem, P., Womann, G. & Beu, A.: Gestaltung von Benutzeroberflächen für AR-Systeme. In Luczak, H., Schmidt, L. & Koller, F.: Benutzerzentrierte Gestaltung von Augmented Reality. pp. 40-54. VDI Verlag. Düsseldorf, 2004.

Reason, J.: A systems approach to organisational error. Ergonomics, Vol. 38(8), S. 1708-1721, 1995.

Reason, J.: Human error. Cambridge, MA: Cambridge University Press, 1990.

Reinert, D., Brun, E. & Flaspöler, E.: Complex machinery needs simple explanation. Safety Science, 45, 579-589, 2007.

Reuth, R. K.-A.: Simulationsgestützte Bewertung des Einflusses menschlicher Fehler in Autonomen Produktionszellen. Shaker Verlag. Aachen, 2003.

Sakas, G. (2002) Trends in medical imaging: from 2Dto 3D. Computers & Graphics, 26, 577–587.

Sarodnick, F. & Brau, H.: Methoden der Usability Evaluation. Wissenschaftliche Grundlagen und praktische Anwendung. Huber: Bern, 2006.

Schmersal: Harmonischer Dreiklang. Ergonomie und Sicherheit an der Schutztür steigern die Produktivität. Der Betriebsleiter, 4, 34-36, 2005.

Schmidt, L., Wiedenmaier, S., Oehme, O., & Luczak, H.: Augmented Reality als neue Form der Mensch-Technik-Interaktion. In Luczak, H., Schmidt, L. & Koller, F.: Benutzerzentrierte Gestaltung von Augmented Reality. pp. 1-14. VDI Verlag. Düsseldorf, 2004.

Skov, T., Borg, V. and Orhede, E. (1996). Psychosocial and physical risk factors for musculoskeletal disorders of the neck, shoulders, and lower back in sales-people. Occupational and Environmental Medicine, 53, 351-356.

Tutherow, G. K.: Operator Interface Evolution. In: B. G. Lipták. Instrument Engineers Handbook. Process Software and Digital Networks. Boca Roton, Florida: CRC Press, 2002.

Urbas, L., Steffens, C., Beu, A. & Jacob, F.: Der Nutzer steht im Mittelpunkt – Usability in der Industrie, Elektrotechnik und Automation, 9, 10-15, 2005.

Venus, M. (2005). Angewandte Psychologie in der Unfallverhütung. Sichere Arbeit, 5, 22-26.

Waters, R. M.: Use of standards to reduce human error. Safety Engineering and Risk Analysis, ASME, Proceedings of the 1994 International Mechanical Engineering Congress and Exposition, Nov 6-11 1994, Chicago, IL, vol. 2, pp. 161-166, 1994.

Weiner, M. (2007). Sicherheitstraining im virtuellen Bagger. Frauenhofer Magazin, 4, 20-21.

Wickens, C. D. & Hollands, J. G. (2000). Engineering Psychology and Human Performance (3rd ed.). Upper Saddle River, NJ: Prentice Hall.

Wiese, B., Sauer, J., Rüttinger, B. (2004). Consumers' use of written product information. Ergonomics 47, 1180-1194.

Wilpert, B. (2007). Psychology and design processes. Safety Science, 45, 293-303.

Yee, K.-P. (2002). User Interaction Design for Secure Systems (ACM). In Proceedings of the 4th International Conference on Information and Communications Security (Lecture Notes in Computer Science 2513), 278–290, Springer-Verlag, 2002. http://zesty.ca/pubs/icics-2002-uidss.pdf

You, H., Young, R., Zimmermann, D., Ekrut, C., Kumar, A. & Lee; M. W.: A usability test for the operating manual of braidmagic. In: Proceedings of the Human Factors and Ergonomics Society. 45th Annual Meeting, pp. 679-701. 2001.

Zühlke, D. (2004). Use-ware-Engineering für technische Systeme. Heidelberg: Springer-Verlag.

LITERATURE REVIEW
THE HUMAN-MACHINE INTERFACE
AS AN EMERGING RISK

Authors:
Topic Centre Risk Observatory:
Eva Flaspöler, Angelika Hauke, Preethy Pappachan and Dietmar Reinert, BGIA, Germany
Tobias Bleyer, Nathalie Henke, Simon Kaluza, Angela Schieder and Armin Windel, BAuA, Germany
Waldemar Karwowski, CIOP, Poland
Simo Salminen, FIOH, Finland
Jean-Christophe Blaise, Laurent Claudon and Joseph Ciccotelli, INRS, France
Lieven Eeckelaert, Marthe Verjans, Karen Muylaert and Rik Op De Beeck, Prevent, Belgium

In cooperation with:
The following sections are based on a questionnaire survey of experts in ergonomics:
Brigitte-Cornelia Eder, AUVA, Austria
Chris Honings and Freddy Willems, Prevent, Belgium
Michael Schaefer and Michael Huelke, BGIA, Germany
Jouni Lehtelä, FIOH, Finland
Javier Badiola and Clotilde Nogareda, INSHT, Spain
Peter Ellwood, HSL, UK
Ian Thomson and Trevor Shaw, HSE, UK

Table of contents

Foreword

The evolution of society and the changing world of work bring new risks and challenges for workers and employers. In this context, the European Risk Observatory (ERO) of the European Agency for Health and Safety at Work (EU-OSHA) conducted four expert forecasts, based on a Delphi methodology, to anticipate new and emerging risks related to occupational safety and health (OSH) risks. One expert forecast was conducted for physical, one for chemical, one for biological, and one for psycho-social risks.

Various emerging factors were identified by the expert forecast on physical risks related to, for example, musculoskeletal disorders, noise, vibration, thermal risks, etc. Among these, the following ergonomics or human factors risks were also identified as emerging:

- Multi-factorial risks (e.g. in call centres: combined effects of poor ergonomic design, poor work organisation, mental and emotional demands)
- Complexity of new technologies, new work processes and human-machine interface (HMI) leading to increased mental and emotional strain
- Poor ergonomic design of non-office visual display unit (VDU) workplaces
- Poor design of HMI (excessively complex or requiring high forces for operation)

The opinion of the forecast's experts underline the crucial role played by ergonomics and especially cognitive ergonomics in ensuring health and safety at the workplace. Interaction with – and indeed dependence on – technology is increasing in almost all occupational fields. Given that poor HMI can have serious consequences, such as occupational accidents and diseases, including stress, its proper inclusion in design equipment and workplace is of utmost importance.

Further evidence of the importance of HMI can be found in the EU-OSHA report on "*Priorities for occupational safety and health research in the EU-25*", which identified research on adequate ergonomic design, including HMI, as a priority for the European Union.

Moreover, the revision of the Machinery Directive[1] focuses attention on ergonomics. It states that "*under the intended conditions of use, the discomfort, fatigue and physical and psychological stress faced by the operator must be reduced to the minimum possible, taking into account ergonomic principles such as … adapting the man/machinery interface to the foreseeable characteristics of the operators.*" (Page 14, 1.1.6 Ergonomics).

This report aims to raise awareness of the importance of adequate HMI as a vital factor for ensuring workers' occupational safety and health.

EU-OSHA would like to thank BGIA as lead authors, the other Topic Centre Risk Observatory authors and the additional experts for their contribution to this report.

The Agency is grateful to its focal points for their valuable comments and suggestions.

European Agency for Safety and Health at Work

---

[1] Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery

1 Introduction

1.1 Human-machine interface (HMI) as an 'emerging risk'

Industrialisation brought widespread use of tools and machines to the workplace and these have steadily grown in number and complexity since that time. Design was driven by technical requirements and rarely took account of the needs and characteristics of the operators. As a result, workers often had to adapt to processes determined by the technical system. Only in the middle of the 20th century did the operator gain more attention in the design process of work systems, leading to changes in design paradigms, culminating over recent decades in a shift to user-centred design.

With the introduction of ergonomics, or human factors, workers' health and safety has been improved by adapting machines and tools to humans' skills, limitations and anatomy. Furthermore, systems of work are increasingly constructed as a socio-technical system consisting of workers, tools, tasks and work contexts (Sarodnick & Brau, 2006). As use of machines – especially computers – increases, so the HMI becomes more prevalent across all fields of work.

Ergonomics is a broad discipline, which ranges from use of anthropometrics in design of equipment and workplace to cognitive ergonomics and the concept of "usability". The focus on user-friendly design of technical systems, machines and tools has increased with the recognition that such systems provide effective support for users, improving not only their effectiveness and efficiency, but also satisfaction (Sarodnick & Brau, 2006). Nevertheless, efficiency and productivity gains are far more common as a reason for applying ergonomic principles compared with employees' wellbeing, despite the longstanding link between ergonomics and safety and health at work (Schmersal, 2005).

In 2005, EU-OSHA completed four expert 'forecasts' of new and emerging risks in the physical, biological, chemical and psychosocial areas. For their task, the experts used the following definition:

- *The risk was previously unknown and is caused by new processes, new technologies, new types of workplace, or social or organisational change; or*
- *a long-standing issue is newly considered as a risk due to a change in social or public perceptions; or*
- *new scientific knowledge allows a long-standing issue to be identified as a risk.*

The risk is increasing if:

- *the number of hazards leading to the risk is growing; or*
- *the likelihood of exposure to the hazard leading to the risk is increasing (exposure level and/ or the number of people exposed); or*
- *the effect of the hazard on workers' health is getting worse (seriousness of health effects and/ or the number of people affected).*

The expert forecast on emerging physical risks (EU-OSHA, 2005) identified the following issues related to ergonomics:

- *Multi-factorial risks (e.g. in call centres: combined effects of poor ergonomic design, poor work organisation, mental and emotional demands)*
- *Complexity of new technologies, new work processes and HMI leading to increased mental and emotional strain*
- *Poor ergonomic design of non-office visual display unit (VDU) workplaces*
- *Poor design of HMI (excessively complex or requiring high forces to operate)*

Research and practical experience show that systems which neglect ergonomics, particularly HMI, are more likely to give rise to occupational diseases, operating errors and accidents. Less visible, but also highly significant are the associated financial costs associated with wasted working time, user frustration, poor corporate image, etc. Poor ergonomic design of products that leads to client dissatisfaction also results in lost sales and damage to companies' image (Dahm, 2006).

In general, the literature focuses on three different starting points in order to ensure safety, health, efficiency, and productivity: the human being, the machine, and the environment. At the same time, these are also identified as risk sources which may jeopardise safety and productivity at work. Human-machine interactions are seen as error-prone and the environment may give rise to unpredictable situations which lead to danger (Montenegro, 1999). When designing an adequate HMI, the working environment as well as the specific properties and qualities of humans and machines must be taken into account. As regards automated processes, machines are more suited than humans to controlling processes, whereas thanks to their creativity and intuition human beings have the flexibility to cope better with unexpected or unforeseen situations (Montenegro, 1999). It is very important, therefore, that tasks are divided appropriately between the human operator and computer-operated technical system, according to the working situation and working environment.

Researchers also agree on the importance of taking sufficient account of operators when creating usable and safe systems as it reduces the likelihood of errors in the design process. Koller, Beu & Burmester (2004) have shown that the operator's opinion on HMI is as important as the tasks for which the product will be used and the technical, physical, and organisational conditions in which the system is to be implemented. Involvement of users in the design process from the start allows adaptation of the end product to the needs of the different target groups of users. Changes identified through operator testing that is carried out only at the end of the design process are usually far more costly to implement than if identified earlier on. A frequently used approach to putting these principles into practice is the "user-centred design process", also known as "usability engineering process" (Koller, Beu & Burmester, 2004), which incorporate feedback loops and evaluation in the HMI design process.

Looking to the future, new HMI challenges will arise as humans work evermore closely with increasingly complex machines and new control interfaces are designed. Recent developments include wearable computers and powered exoskeletons, such as Robot Suit HAL[2], which is already on the market. New interfaces include gesture technology; brain-computer interfaces, which allow control using brain waves; haptic technology (e.g. touch screens); and speech recognition software.

1.2 Scope of this report

The aim of this report is to follow-up the expert forecast on physical risks and to further investigate HMI as an emerging risk. Based on a literature survey, analysis of survey data and a small expert survey, the report explores whether complexity of HMI leads to safety and health risks such as increased mental and emotional strain for users. In so doing, it addresses the following questions: To what extent is user-centred design applied in the world of work? Are there barriers to the application of user-centred design? What HMI-related risks are jeopardising safety and productivity at work? Which methods and standards favour user-centred design and are they applied in practice? Are there groups of workers which are especially affected by poor HMI design?

The scope of the report is mainly restricted to HMI in terms of "machinery" as defined by European directive 98/37/EC (the "machinery directive")[3] and puts only a small emphasis on the human-computer interface, which is a large topic in its own right. HMI includes a broad range of fields that, although relevant to health and safety at work, are beyond the scope of this study.

Human-computer interaction (HCI) comes under the umbrella of HMI, but it is a well-developed research field in its own right that focuses mainly on improving computers' usability. HCI is only covered in this report insofar as a poor HCI can contribute to stress.

Operational or system safety, or reliability engineering, considers how accidents can result from the interaction of different parts of a system with each other and with their environment. Rather than looking at occupational accidents, it is concerned principally with the avoidance of major accidents that can affect large numbers of people, both workers and public. The part played by human operators in systems – especially those related to major hazards, such as chemical plants, nuclear facilities, airliners, etc. – is affected to a great extent by the HMI. Research fields such as human error and human reliability analysis consider HMI, but are beyond the scope of this report, which is concerned with safety as it affects the operator.

HMI can also be taken to include physical ergonomics and the prevention of musculoskeletal disorders; but again, this is a large field in its own right that has been well covered by EU-OSHA in previous studies[4].

---

[2] http://www.cyberdyne.jp/english/index.html

[3] Directive 98/37/EC of the European Parliament and of the Council of 22 June 1998 on the approximation of the laws of the Member States relating to machinery as amended by Directive 98/79/EC

[4] http://osha.europa.eu/en/topics/msds; http://osha.europa.eu/en/riskobservatory/risks/forecasts/index_html/physical_risks/

1.3 Definitions

1.3.1 Machinery

The term “*machine*” has various definitions; some are sophisticated, others quite simple. The point at which tools or auxiliary means can be characterised as machines is complicated and leads to complex descriptions. Examples of broad definitions are those given by the Concise Oxford Dictionary:

”*An apparatus using or applying mechanical power, having several parts each with a definite function and together performing certain kinds of work.*”

And Charwat (1992):

“*[An] umbrella term for all technical devices which are used by humans for a specific purpose. Machines can be vehicles, devices, aggregates/units, computer or their combination (e.g. automated systems)*” (p. 285).

At the other end of the spectrum is the precise definition used in the machinery directive, which was enacted to protect users against risks caused by machinery:

- “*… an assembly of linked parts or components, at least one of which moves, with the appropriate actuators, control and power circuits, etc., joined together for a specific application, in particular for processing, treatment, moving or packing of a material,*
- *an assembly of machines which, in order to achieve the same end, are arranged and controlled so that they function as an integral whole,*
- *interchangeable equipment modifying the function of a machine, which is placed on the market for the purpose of being assembled with a machine or a series of different machines or with a tractor by the operator himself in so far as this equipment is not a spare part or a tool;…*” (Directive 98/37/EC, p. 5).

Among the devices excluded from this directive, are:

- “*machinery whose only power source is directly applied manual effort, unless it is a machine used for lifting and lowering loads …*
- *… means of transport, i.e. vehicles and their trailers intended solely for transporting passengers by air or on road, rail or water networks, as well as means of transport in so far as such means are designed for transporting goods by air, on public road or rail networks or on water. Vehicles used in the mineral extraction industry shall not be excluded …*” (Directive 98/37/EC, p. 5).

Although the machinery directive excludes computers from its definition, this is not the case for researchers in the field of human factors, ergonomics, and HMI, as stated by Carey (1998) “*The human factor engineer is concerned with many machines other than the computer…*” (p. 27).

1.3.2 Human factors

Asbjørnsen (1994) cited by Einarsson (1999) explains human factors as “*the relationships and interactions between a system and its human elements and between the human elements themselves in a system or its adjacent organisation. The integral of all human factors in a corporation constitutes the corporate psychology. This makes up the corporate culture and the social resources in the corporate competitive position.*”

According to Wickens and Hollands (2000), the concern of the field or discipline called human factors is “*designing machines to accommodate the limits of the human user*”. They further define the elementary objectives of human factors engineering as the reduction of error, the increase of productivity and the enhancement of “*safety and comfort when the human interacts with a system*”.

1.3.3 Human-machine interface

Descriptions of HMI can be broad, such as that given by Tutherow in Lipták (2002): “*Although it can refer to any type of interface device, the term HMI usually refers to the display, computer, and software that serve as the operator’s interface to a controller or control system.*” (p. 288).

More precise definitions are provided by Baumann and Lanz (1998) as well as by Charwat (1992). They describe HMI as the part of an electronic machine or device which serves for the information exchange between the operator/user and the machine/device. HMI consists of three parts which are (1) operating elements, (2) displays, and (3) an inner structure. The *inner structure* compasses hardware and software (electronic circuits and computer programmes). *Displays* show and transfer information about the machine to the user (for instance by means of graphical displays) and *operating elements* transfer information from the operator to the machine via for instance push buttons, switches, adjusting knobs, etc..

1.3.4 Human-machine interaction

Humans and machines interact and affect one another; however, compared to communication between humans, the media available are restricted only to the above mentioned displays and operating elements. In this context humans can only use physical input devices, such as buttons, touch-screens, keyboards, or mouse. For their part, machines can give information visually (e.g. as pictures and characters), acoustically (verbal or nonverbal) or physically (e.g. vibration).

Complex interaction between humans and machines is limited by the fact that whereas humans have natural intelligence, which enables us to interpret situations according to the context, this ability is absent in most machines and very restricted in even the most advanced. In general, software does not allow machines to adapt to unforeseen conditions, so computers are limited in their actions and cannot adapt to given situations. Nonetheless, humans often expect the machine to communicate in the same way as they do and get frustrated or angry when it does not (Dahm, 2006).

1.3.5 Ergonomics

Ergonomics deals with human work and the optimal adaptation of work to the properties and skills of the humans involved in the working system. Thus, the focus of ergonomics is the human and his needs in fulfilling his tasks; including the ‘need’ to be protected from injury and ill health. In order to protect workers, ergonomists develop new methods and design the working environment in a way that supports workers in achieving their objectives effectively and efficiently (Dahm, 2006). This definition already shows the close relationship between ergonomics (the anatomically adapted design of tools/machines and supplies for work and of working procedures), safety at work and productivity (Schmersal, 2005).

While ergonomics traditionally focused on anthropometric design of machines, cognitive ergonomics became important in the mid 1970s. The field of cognitive ergonomics covers communication aspects, for example, in the interaction with machines (e.g. software ergonomics) (Charwat, 1992).

1.3.6 Usability

“Usability” is defined in the norm ISO 9241-11[5] as the “*extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use*" (p. 2). Thus, usability is an essential part of (cognitive) ergonomics, which permits humans to use machines and tools efficiently, effectively and in a way that is satisfying (Sarodnick & Brau, 2006).

---

[5] ISO 9241-11:1998 Ergonomic requirements for office work with visual display terminals (VDTs) Part 11: Guidance on usability

2 Who is exposed to HMI-related risks?

2.1 Increasing importance of HMI

The use of complex machines, processes and systems is increasing in all sectors, but there is also some evidence that the pace of change is slowing. The drive for automation and computerisation stems principally from increasing labour costs and from higher quality requirements and standardisation. This development should be seen positively so long as it results in better products and does not affect workers' health.

Production technology, particularly manufacturing machines in the metal industry, is especially affected by increasing complexity and increasing use of complex machines, processes or systems. An increase in operators' mental workload and consequently in the risk of errors, means that HMI is of particular relevance to high-risk industries, such as the chemical, electric or nuclear energy industry and transport. Automation and increasing complexity mean that control room operators have to handle complex data and alarms and to take safety-critical decisions under the pressure of unexpected and rapidly changing hazardous situations.

In general, technical installations are becoming more complex in industrial processes ranging from automobile-related industries to biotechnology. Increased complexity can be found in, for example, cranes, elevators and other transport systems, self-steering buses, autonomous trains, vehicle with extensive driving aids, such as adaptive cruise control and autonomous braking and parking.

Other HMI-susceptible areas include workplaces related to operating and monitoring (especially if the process itself is not visible), such as waste management and disposal engineering machinery, public and administrative systems, maintenance sector, equipment used in the electrical energy sector, handling systems and data process installations.

2.2 Number of machine users

Eurofound's[6] fourth European working conditions survey (EWCS) carried out in 2005 shows that one in four jobs involve working all, or almost all, of the time with computers, however, no comparable figures exist for machines.

At national level, information is available from the 2005/2006 German BIBB-BAuA survey of 20,000 employees[7]. This showed that 8.2% of respondents work with machines (excluding computers, as defined in directive 98/37/EC), which when applied to the whole working population of Germany, indicates that 5.5% of workers, or 1.82 million, work with machines.

Working conditions of machine users were investigated in the BIBB-BAuA survey using a sub-sample (*n*=1104) of machine users and the results are described in the following sections.

2.3 Type of machine and size and sector of enterprise

As can be seen in Figure 1 below, 70% of the BIBB-BAuA sample used one of three types of machine: "automatic", "manually driven" or "machines, plant (in general)".

---

[6] European Foundation for the Improvement of Living and Working Conditions www.eurofound.europa.eu

[7] BIBB/BAuA – Erwerbstätigenbefragung 2006 www.bibb.de/de/wlk21738.htm

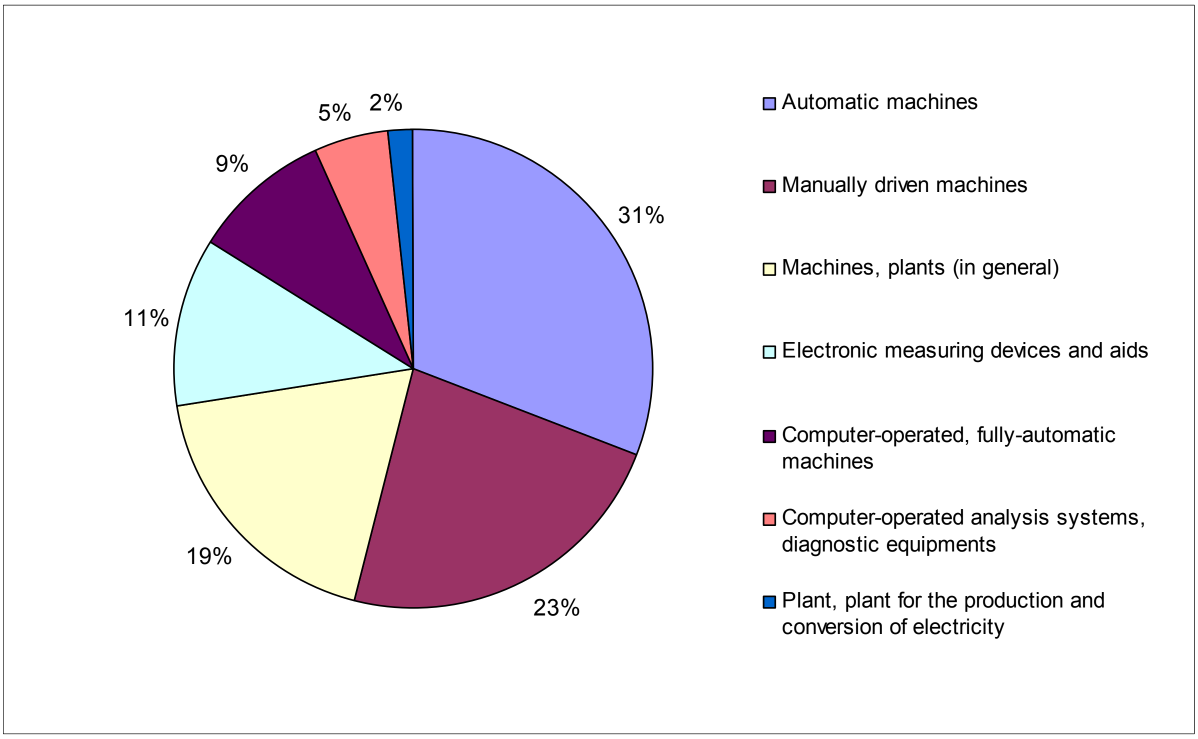


Fig. 1: Type of machine used (machine users' sample, BIBB-BAuA survey 2005/2006)

Most machine users work in companies with 10 to 49 employees (28.6%), in companies with 50 to 249 employees (24.7%), and in companies with up to 9 employees (18.7%). The share of machine users working in companies with 10 to 499 employees is slightly higher than in enterprises in general.

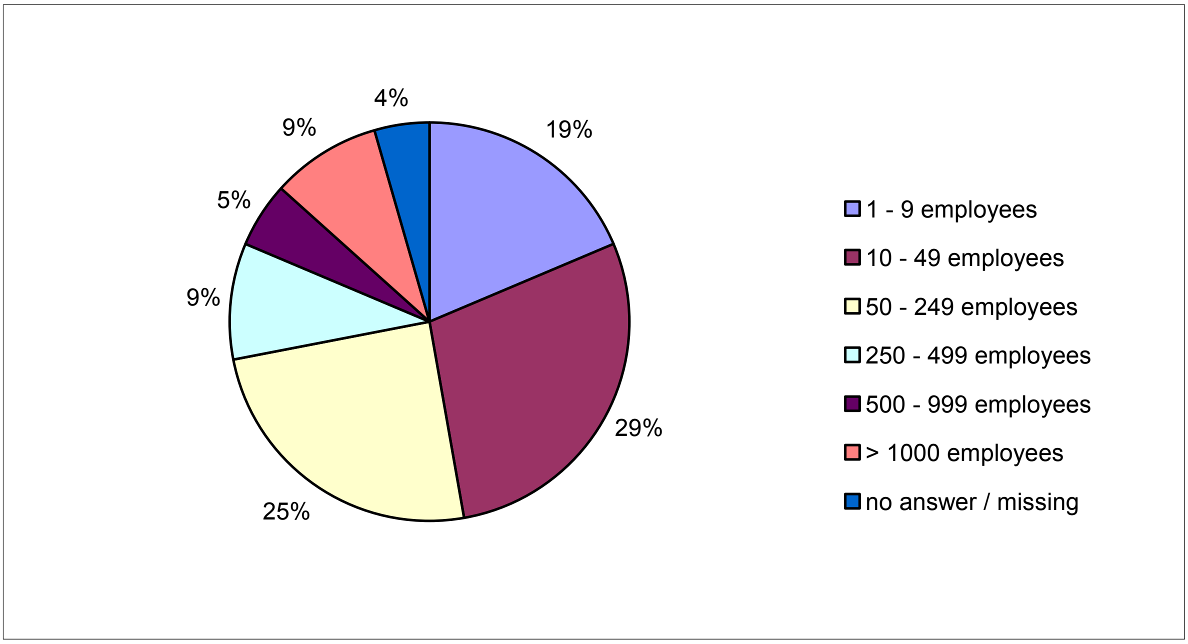


Fig. 2: Size of companies employing machine users (machine users' sample, BIBB-BAuA survey 2005/2006)

Data from Eurofound's 2005 EWCS show that – as would be expected – the largest proportion of workers whose pace of work is dictated by a machine are in manufacturing (41%). The next highest sectors, with approximately a quarter of workers affected, are construction, transport and communication, and agriculture (see figure 3 below).

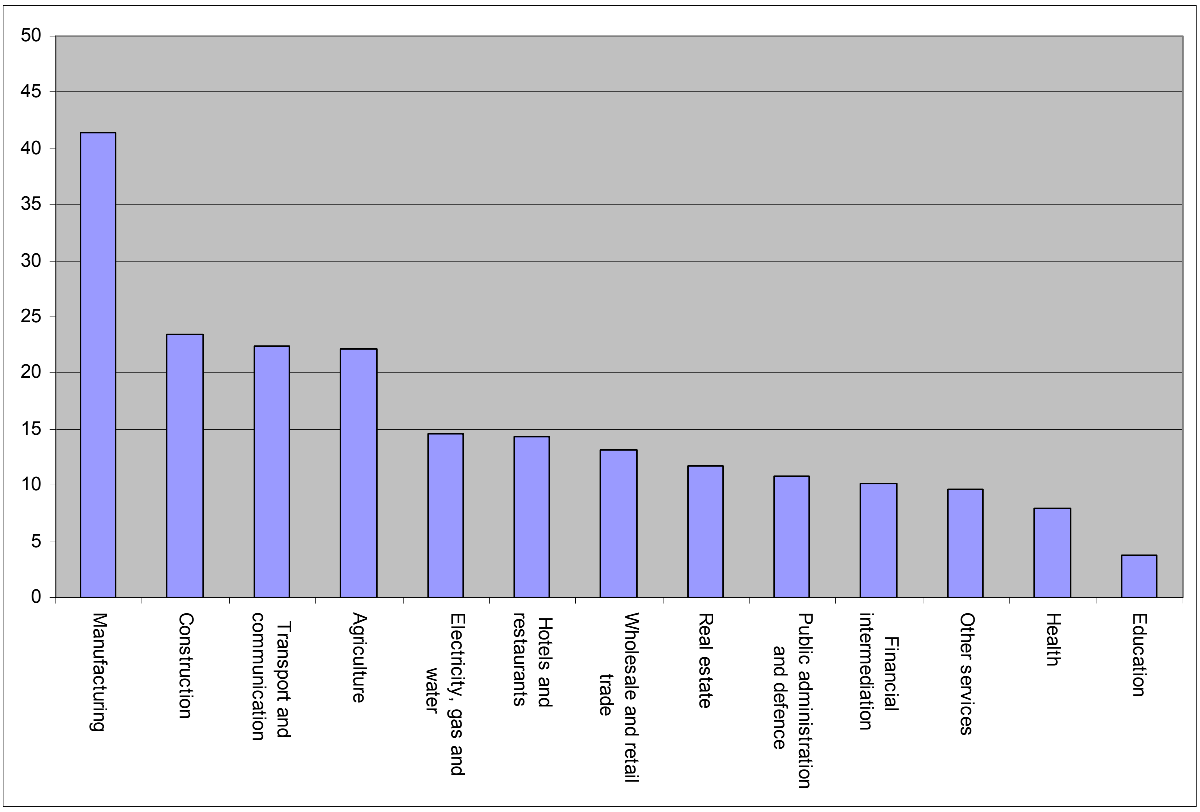


Fig. 3: Proportion of workers whose pace of work is dictated by a machine (Eurofound EWCS 2005)

2.4 Sex, age and skill level

In the BIBB-BAuA sample, more men than women (65.2% vs. 34.8%) work with machines.

The age distribution in the group of machine users is equivalent to the age distribution in the general working population, however, research indicates that age and especially experience of machine operators is an important factor in accident risk. According to Backström and Döös (1995), about three quarters of the victims had one year or even less experience. Other studies estimate that approximately one quarter of the injured persons have three months or less experience, another quarter had four months to one year of experience and almost half of the victims had two years or more experience (Döös, Backström and Sundström-Frisk, 2004).

Having gained a good understanding of how a machine works, experienced operators are at least risk of suffering an accident as a result of HMI. In contrast, workers who work with the machine just occasionally and are less likely to receive instruction or training are at high risk. This group includes maintenance workers, temporary workers, home-workers, tele-workers, seasonal workers, as well as operators of machinery for hire. Similarly, when a new work process or technology is introduced – especially if done so too quickly – the risk of problems associated with HMI increases.

Older workers are more likely to experience problems in working with new technology. They may find it difficult to change their habits and may need specific training and coaching. HMI should be tailored to their abilities. However, it is not only older workers who may encounter difficulties using new technology. Many people, for example, either lack experience of using computers or simply do not want to use them. As a result, these workers are more reserved and hesitant when interacting with computers and are more at risk from inadequate use of HMI.

Among those working at machines, the proportion of unskilled and semi-skilled workers (26.3%) is higher than in the total population (14%). In the sample, 40% of the machine operators are skilled workers, 12.7% are qualified employees/civil servants, 6.1% are unqualified employees/civil servants, 4.5% are executive staff/civil servants and 1.6% are master craftsmen/head foremen. For 9%, no classification is available. Additionally, some workers may be at greater risk from a poor HMI because other limitations such as disability, poor knowledge of the local language, low level of education, or lacking experience of technology and complex systems.

Greater specialisation means that fewer workers are able to understand how to work with the specific complex machine. Maintenance activities, in particular, pose a challenge as a lot of complex systems need human assistance or intervention. The design of many machines considers only operation under normal conditions; as a consequence, when maintenance needs to be carried out, risks related to such complex systems are not predictable and can be of different nature.

Furthermore, the study found out that employees working with machines are mostly full time workers (79.5% vs. 20.5% part-time workers). 45.9% of these full time workers work between 40 and 47.9 hours a week. Regarding their working contracts (fixed-term and indefinite) percentages are comparable with the entire population.

According to Döös and Backström (1994) working in hazardous areas of automated machines puts workers at increased risk. They state that around two-thirds of injured workers sustained from automated machines are production workers or operators, whereas maintenance staff only makes up 10% of the injured workers.

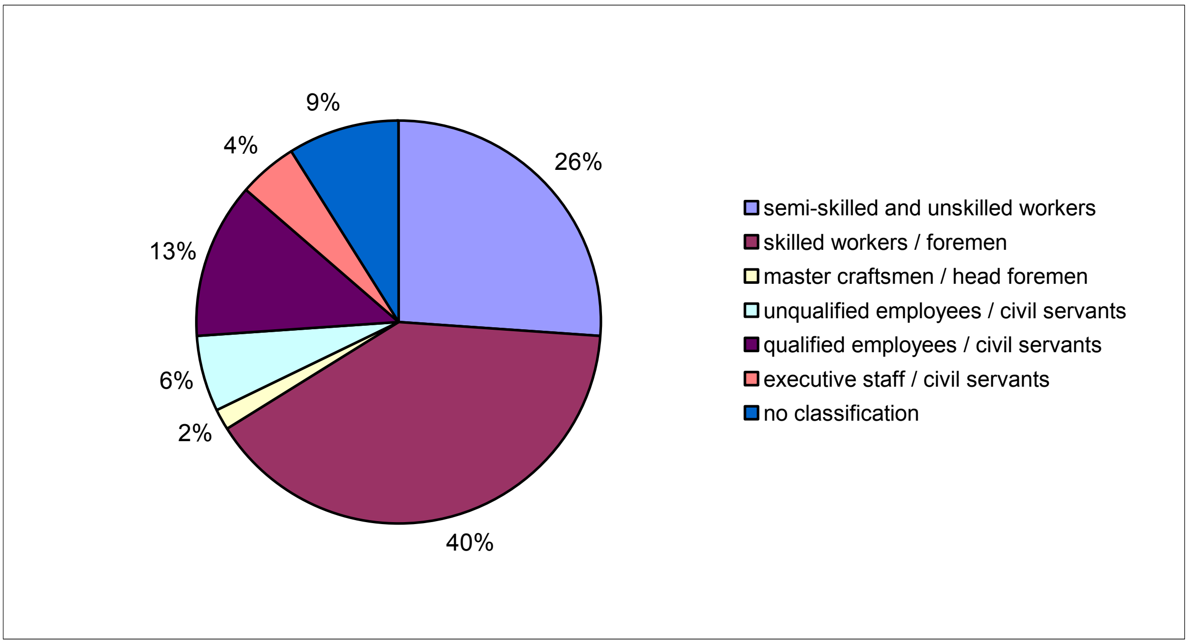


Fig. 4: Skill level of machine users (machine users' sample, BIBB-BAuA survey 2005/2006)

2.5 Working conditions

The BIBB-BAuA data suggest that, in general, working conditions with respect to ergonomic aspects are poorer for machine users than for the total population (see Figure 5 below). Compared with the general working population, machine users are more exposed to repetitive work, working in an upright standing position and carrying heavy loads.

Fig. 5: Machine users exposed 'sometimes' or 'often' to selected OSH risks compared with the total working population (BIBB-BAuA survey 2005/2006)

Figure 6 below shows that machine users are more likely than the general working population to be exposed to fumes, dust, gas, vapour, cold, heat, wet, draughts, noise, dangerous substances, radiation, oil, grease and dirt, or to have to wear personal protective equipment or clothing.

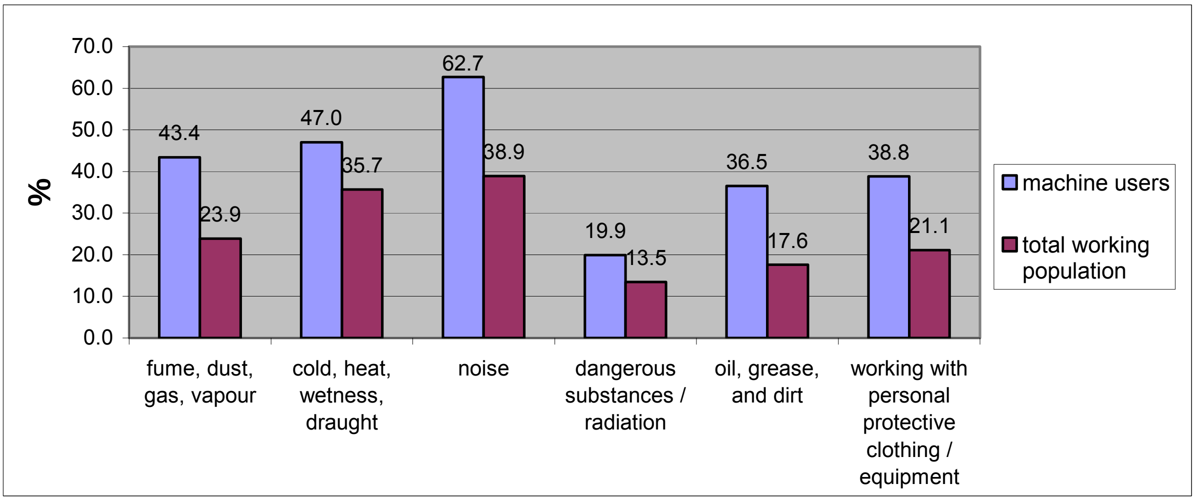


Fig. 6: Machine users exposed 'sometimes' or 'often' to selected OSH risks compared with the total working population (BIBB-BAuA survey 2005/2006)

Further analysis of the data shows that machine workers are more affected than other workers by whole-body and hand-arm vibration (26.4% vs. 11.3%), high noise levels (35.8% vs. 15.3%) and having to exert high dynamic and static forces (30.2% vs. 17.1%).

With respect to psychosocial risk factors, the data indicates that machine operators have significantly lower decision latitude concerning both work organisation and breaks than other types of worker and slightly lower influence over their amount of work.

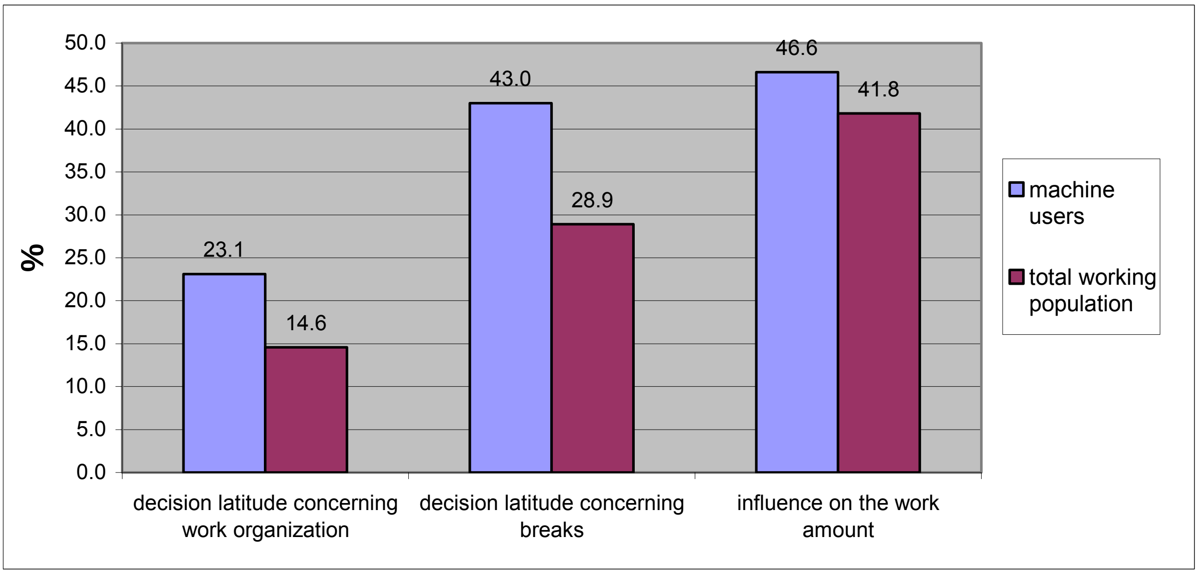


Fig. 7: Machine users 'never' or 'rarely' given decision latitude compared with the total working population (BIBB-BAuA survey 2005/2006)

2.6 Health outcomes

Machine workers are slightly more likely to state that they suffer from back pain than employees in general and are more likely to suffer from pain in their arms and hands, knees and legs or feet. They are also more likely to experience hearing problems such as occupational deafness or tinnitus. In contrast, they are slightly less likely to suffer from headaches or pain in the neck and shoulder than the rest of the working population, where the influence of prolonged working with VDUs can be seen.

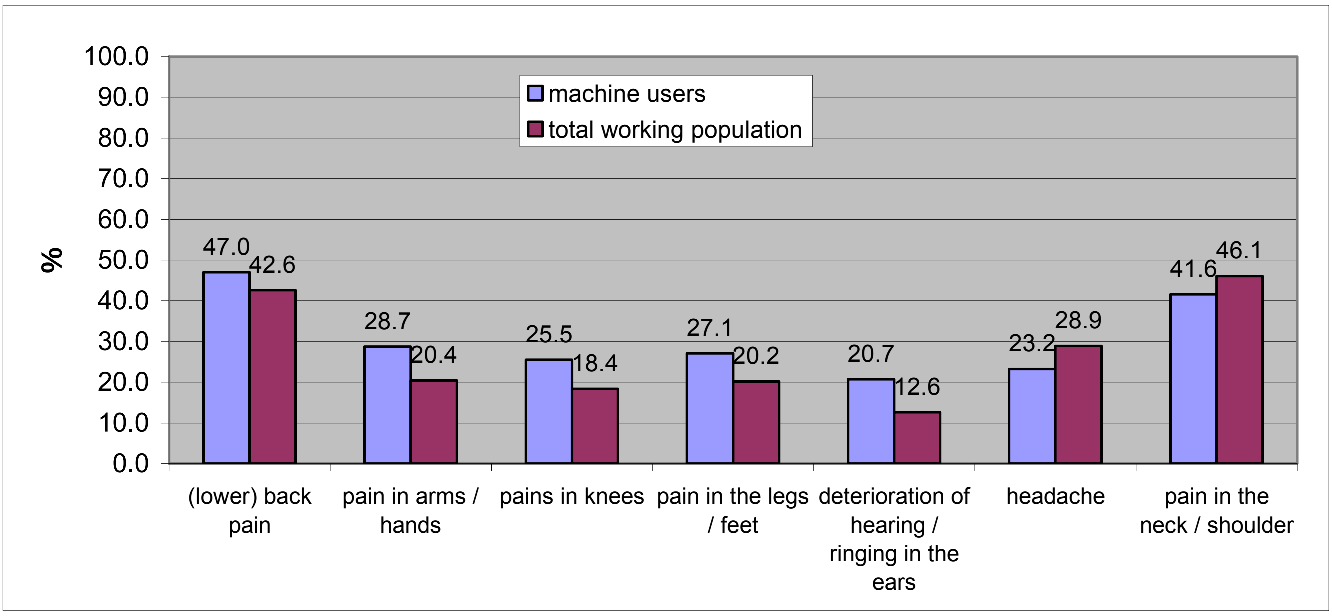


Fig. 8: Machine users' health complaints in comparison to the total working population (BIBB-BAuA survey 2005/2006)

3 Importance of HMI in relation to OSH

3.1 Introduction

Greater automation can have the following consequences for workers' health and safety:

- Psychosocial and musculoskeletal problems caused by reduced physical activity, more static postures and higher mental work load (e.g. when monitoring and controlling); less privacy at work (as technology allows closer and more intrusive supervision); and more decision-making problems.
- Increased risk of accidents resulting from human errors; usually affecting the user, but – especially in the case of high-risk industries - having the potential for serious consequences beyond the operator to include fellow workers, the wider community and environment.

Technical progress over the last 50 years means that production processes are using machines which are increasingly powerful in terms of speed, quality, and flexibility (Becker, 2006). This expansion is evident in almost all sectors, but especially so in manufacturing, air industry, construction (e.g. in-cab devices), production sector and healthcare sector (e.g. computer-aided surgery), (EU-OSHA, 2005).

Linked to increasing mechanisation and complexity is a growth in the use of computer-based automated systems in place of human operators to control highly complex technical systems. However, while computer-based systems offer greater reliability and the potential for greater control, they cannot at present match the flexibility of the human operator. It is computers' inability to cope with unforeseen circumstances that makes the human operator indispensable in complex systems. Particularly at times of failure, systems depend on human operators' intelligent, context-based thinking (Reason, 1990, Nachreiner, Nickel & Meyer, 2006).

Technological developments allow a great amount of information to be presented and combined and for many tasks to be carried out simultaneously. Consequently, operator tasks are frequently reduced to those of start up, monitoring and control of processes via digital media. Relatively small errors on the part of the operator have the potential for serious consequences, so additional safety systems are built in, which often result in the operator being overloaded with information. Conversely, changing a job from one of operating machinery to one of monitoring, control and surveillance, can result in it lacking in content and being regarded as boring and monotonous.

The high proportion of employees working with machines or computers means that proper design of the HMI is essential. Poor design of HMI can give rise to occupational diseases, such as stress or musculoskeletal disorders, as well as to occupational accidents. The potential cost to an employer due to reduced productivity, damaged reputation, or users' dissatisfaction is clear.

3.2 Increased levels of mental strain and stress

Automation should result in better working conditions, however, it can sometimes result in control systems that are more complicated to operate and it can change working methods so that demands increase with regard to stamina, time pressure and the pace of work. As automation reduces the number of operators, those remaining are increasingly isolated and have to act and communicate with the help of the new technology. Additionally, their workload may increase and the impact of errors is likely to be greater. The changes in how work is organised mean that teamwork loses importance and operators increasingly have to be experts in many different fields and bear more responsibility; this may increase task variety, but can also increase mental work load.

Poor design of HMI can lead to bad temper and even to negative health effects. For instance, Sarodnick and Brau (2006) report that frustration caused by the computer can lead to depression.

The neglect of human factor design principles in interface design, particularly where it results in system failure, is a major cause of increased mental strain, which can result in stress (Nachreiner et al., 2006). IT problems affect many workers and can clearly contribute to increased mental strain. In a survey of 1,250 UK workers (Ipsos-MORI, 1999), 23% of respondents said they had to interrupt their work on a daily basis due to IT problems and over 10% of those who suffered daily interruptions stated that stress caused by IT strongly affected their relationships at work. 75% of office workers in another study (Oberhuber, 2007) had resorted to violence against their computer.

Nachreiner et al. (2006) give examples of how failure to apply dialogue principles can result in higher mental workload:

- Displays that show a value without giving comparison levels or an interval indicating a range of non-critical values oblige the user to learn and memorise how to interpret the indicated value with respect to hazards.
- Inconsistency with user expectations or common conformities (e.g. if an emergency stop button were to be given a colour other than red).
- Ambiguous information (e.g. abbreviations which may be interpreted in two different ways). Nachreiner et al. (2006) showed that an unfamiliar alarm signal increased mental stress while the operator tried unsuccessfully to identify the reason for the alarm.

Nachreiner et al. (2006) conclude: "*…inadequate ergonomic design of the interaction interface increases control difficulty… or impedes successful control, which is associated with increased mental work load for the operator and increased strain, thus leading to less effective and less efficient process control.*" (p. 23).

3.3 Occupational accidents

According to NIOSH, machine-related injuries were the second leading cause of occupational fatalities in the United States between 1980 and 1995 and between 1992 and 2001, an average of 148 fatal and 318,488 non-fatal occupational caught-in-running-machinery-accidents occurred per year.

In 2000 in Austria, 8% of all occupational accidents occurred at machines, of which 76% were attributed to human error (68% errors in use of the machine and 8% removal of protective devices), 17% to machine deficiency, 5% to malfunction of a machine component, and 2% to modifications carried out on the machine. The removal or tampering with protective devices is often linked to maintenance, cleaning, repairing, and programming (Österreichisches Bundesministerium für Wirtschaft und Arbeit, 2001).

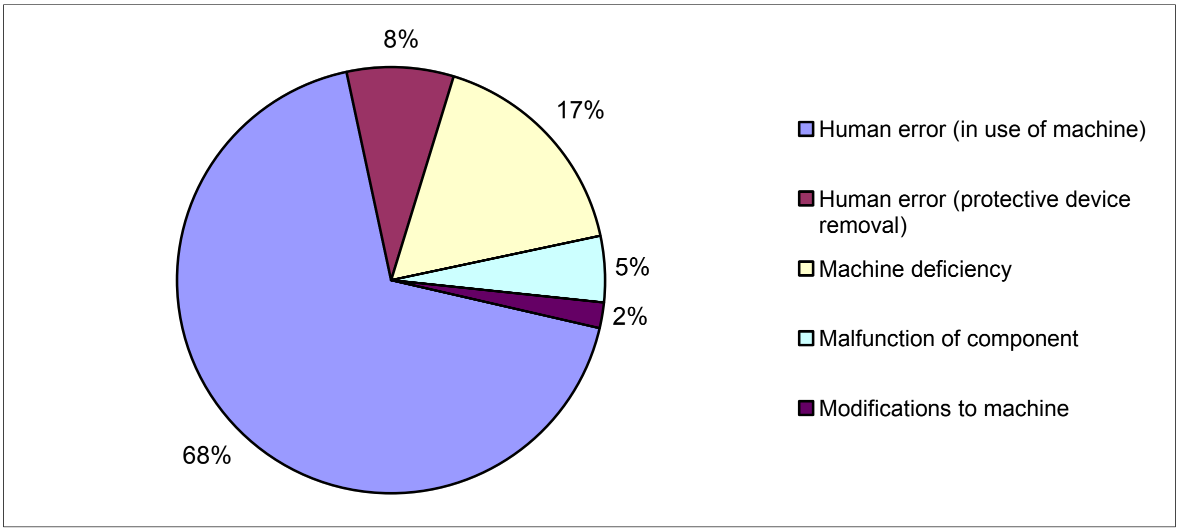


Figure 9 – Causes of accidents at machines in Austria (2001)

Similarly, Backström and Harms-Ringdahl (1984) found that 55% of machine-related accidents resulted from operational failure, whereas 20% were caused by technical failure and 12% by technical as well as operational failure. Other studies, in contrast, attribute higher proportions of accidents to technical failures (Backström and Döös (1997) estimate that 84% are due to machine failure and in an earlier study (Döös and Backström, 1994), the same authors found that 86% of accidents with automated equipment are due to technical causes).

A survey of safety inspectors and employees in the industrial sector by the German statutory accident insurance (HVBG, 2006) showed that tampering with safety devices is a significant problem (37% of cases) and this is supported by research showing that safety barriers are sometimes removed to facilitate the work process (Mattila, Tallberg, Vannas and Kivistö-Rahnasto, 1995). Such safety devices comprise part of the HMI, which if not well designed, may be perceived by operators as a hindrance. Other factors such high production targets or pressure to increase output can contribute to this perception.

Other causes of accidents related to HMI include inadequate operation and maintenance instructions; designs that do not let the operator see the danger zone (Backström & Harms-Ringdahl, 1984; Mattila et al., 1995); and open access to hazardous areas of the work station (Mattila et al., 1995). Unexpected movements of machines (Backström & Döös, 1997; Backström & Harms-Ringdahl, 1984; Mattila et al., 1995) or not stopping a malfunctioning machine system also present accident risks (Backström & Harms-Ringdahl, 1984). Moreover, inadequate workplace design such as an unsafe machine which does not stop when removing safety barriers, an emergency stop which cannot be reached by the operator (Mattila et al., 1995) or confusing control status indicators leading to an unintentional contact with a switch (Backström & Harms-Ringdahl, 1984) can be hazardous for workers.

Since some operators are simply not aware or do not know anything about the functioning of the system they work with (Backström & Harms-Ringdahl, 1984), it is essential that the operator is able to assess the information and to observe the work process (Mattila & Kiviniitty, 1993).

3.4 Human error

Deficiencies in the HMI significantly increase the likelihood of human error, which can easily result in occupational accidents. Much less likely to occur, but with far graver consequences, human error can also result in major accidents or even disasters. It is this latter aspect that accounts for the extensive study of HMI in the fields of system safety, reliability engineering and human reliability analysis.

3.4.1 Definition

From a technical perspective, “human error” can have thee different focuses: it can focus on the cause of an outcome, on an action leading to an outcome, or on the outcome itself (Hollnagel, 1998). In addition, the “human error” can be defined as an omission or inaccurate execution of a planned sequence of mental or physical activities, if the error is not a result of other system components promoting the error. If a certain degree of imprecision is reached, it is likely to result in an undesirable system status (Reuth, 2003).

Human errors can be analysed using taxonomies, which demand different criteria (Reuth, 2003):

- Identification of the underlying *causes* of incidents
- Consideration of human error *mechanisms*
- Identification of *deviation from existing rules / manipulation*
- Understanding *safety relevant consequences*
- Understanding *technical consequences* in production processes
- Consideration of the *frequency* of the incidents
- Identification of the *relevant actions to resolve a dysfunction*

Objective classification of incidents with regard to the taxonomy is essential in order to find out why human error happened and how it can be prevented in future. (Reuth, 2003).

3.4.2 Causes of human error

According to Park (1997), there are three main types of causes of human error:

1. Complexity of task (tasks differ with regard to their demand on mental resources),
2. Situations (some are more likely to lead to errors). The following characteristics increase the probability of human errors:
    - Inadequate workplace design,
    - Inadequate design of work equipment and its HMI,
    - Poor environmental effects,
    - Inadequate learning and working aids and
    - Inadequate safety instructions.
3. Preconditions with regard to human capacities.

The likelihood of human error is affected by individual characteristics such as age, sex, intelligence, perceptive abilities, physical state, patience, experience, knowledge, motivation, emotion, stress and other social factors (Park, 1997). The combination of stress and inexperience can lead to an exponential increase in human errors (Miller & Swain, 1986). These factors are also named *“Performance Shaping Factors”*, as they strongly influence human information processing (Bubb, 1994). External Performance Shaping Factors (age, sex) can be distinguished from internal Performance Shaping Factors (motivation, patience).

3.4.3 Human risk perception and evaluation

The way in which human beings perceive and evaluate risks plays an important role with respect to safe behaviour at work. Human risk perception depends on different perspectives: the source of the risk, the context in which it occurs, and the persons affected (Haller, 2003). If an investigation is carried out into the cause of an accident, this has been found to have a positive effect on risk perception. Döös, Backström, and Samuelsson (1994) found that, as well as improving risk perception among those involved, accident investigations resulted in better knowledge about accident hazards in automated production; made communication easier; and improved information about job routines. Accident investigations also help focus attention on OSH and facilitate the introduction of additional accident prevention measures.

3.4.4 Procedures to analyse and evaluate human reliability

As the costs of human error can be very high, it is important to know what has to be done and what can be done to reduce the probability of human error in potentially hazardous situations (Reason, 1990).

Tools such as probabilistic risk assessment, which are used to assess risks associated with complex technical systems (e.g. chemical plants, nuclear power plants, oil and gas installations), depend on methods such as human reliability analysis to take account of human error in the system

3.4.5 Decision-making

According to Hollnagel (1998), decision-making should in principle follow information processing models. Firstly, alternatives are identified, then they are compared, the best one is selected and finally the consequences of the decision are verified. Field studies show, however, that in practice, people tend to define principle objectives, outline a few obvious alternatives, select a reasonable compromise and then they repeat the task if the results are unsatisfactory. From a safety perspective, this latter approach is not ideal.

Chapter 4 describes design principles and methods which take into account these factors influencing human behaviour with regard to safety and health at the workplace. These methods adapt to the way human beings perceive their environment, process information, and make decisions. Likewise they adapt to human skills and consider their limitations as well.

3.5 Musculoskeletal disorders

Poor HMI is an important risk factor for developing musculoskeletal disorders and this has been linked to the increased incidence of MSDs experienced by industrial nations over the last decades (e.g. EU-OSHA, 2009; Marcus & Gerr, 1996; Skov, Borg & Orhede, 1996). Static postures and repetitive movements contribute, for example, to computer users suffering increasingly from MSDs of the upper limbs (Höhne-Hückstädt, Keller Chandra, Ellegast & Schäfer, 2007). (Gerr, Marcus, Ensor, Kleinbaum, Cohen, Edwards, Gentry, Ortiz and Monteilh, 2002) showed that MSD symptoms in the neck and shoulder occurred among computer users in 58 cases/100 person-years and hand and arm MSD symptoms in 35 cases/100 person-years. Other examples of jobs that are associated with high incidence of MSDs are crane operators and sewing machine operators (Ellegast, Lesser, Herda, Hoehne-Hückstädt, Schwan and Kraus, 2006; Ditchen, Ellegast, Herda & Höhne-Hückstädt, 2005). In order to reduce the risk effectively, ergonomic principles dictate that design of the HMI should include working place, work organisation, working context, and work content (INQA[8]).

---

[8] Initiative Neue Qualität der Arbeit (www.inqa.de/)

4 HMI as a way of improving health and safety

4.1 User-centred design

Design and development of products has shifted from being technology-oriented to user-oriented. Zühlke (2004) describes how, until the 1970s, industrial control devices consisted only of hardware, to which new functions could only be added by developing additional, complex components. In the mid 1970s, the advent of controls based on microprocessors and the availability of inexpensive, repeatable software, made it relatively simple to add new functions. However, the limits to this technology soon became apparent in the form of high software development and maintenance costs and users being overwhelmed by new functions. The so-called 'software crisis' ensued and, partly as a response to this, several ISO and IEEE standards were established.

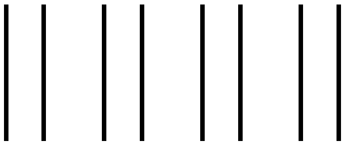
More recently, Zühlke identifies a development, termed an 'operability crisis' or 'usability crisis', whereby users are unable to cope with the complexity of products and do not use all of the functions provided. The HÜMNOS-Project[9], launched in 1995, found that operators typically use only half of a machine's available modes of operation and most users required training of up to three weeks. The main reason for this was found to be the development of operating systems based on a technology-oriented or function-oriented paradigm while the user proceeded with a task-oriented paradigm.

Adoption of user-oriented design and use-ware engineering in the late 1990s is identified by Zühlke as a reaction to the abovementioned operability or usability crisis. The focus of the design process is no longer based solely on functional requirements and what is possible technically, but concentrates on the requirements of the intended user. Users are no longer forced to adapt the way they work to the product; instead it is designed according to their typical work preferences. Use-ware engineering is a multidisciplinary field, which recognises the necessity of bringing together electrical and software engineering as well as industrial psychology, cognitive psychology, and occupational medicine. By using a user-driven and participatory design paradigm, manufacturers take account of user needs from the start of the design process. This approach uses basic psychological and perceptual principals such as the so-called "Gestalt Laws" in product design and particularly in visual interface design.

4.1.1 Gestalt laws/principles

Yee (2002) points out, that graphical user interfaces often rely on associations between graphical elements like labels, checkboxes and lists. Their positioning is essential for the correct allocation of command descriptions and the buttons that complete it. Therefore, Yee (2002) recommends application of the Gestalt principles of perceptual grouping in user interaction design.

Gestalt psychology describes principles of perception which determine the way in which objects are perceived. Gestalt laws or principles do not act in isolation, but rather tend to influence each other, so that the final perception is a combination of all of the Gestalt laws acting together.

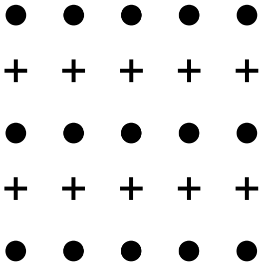


Gestalt law of proximity

Fig. 9 (Anderson, 1996, p. 43)

Spatial or temporal proximity leads to a perception of a collective or totality. Elements that are closer together will be perceived as a coherent object.

We rather perceive four pairs of lines than eight single lines.



Gestalt law of similarity

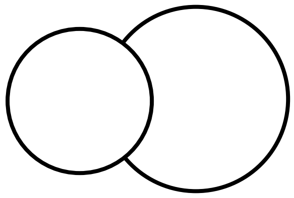
Fig. 10 (Anderson, 1996, p. 43)

Similar elements are perceived as being part of the same form. The similarity might depend on relationships of form, colour, size, or brightness.

We are prone to perceive the pattern as rows of circles which alter with rows of crosses. Similar objects are grouped together.

---

[9] Funded by the German ministry for research (BMBF) and co-ordinated by the German machine tool builder association VDW

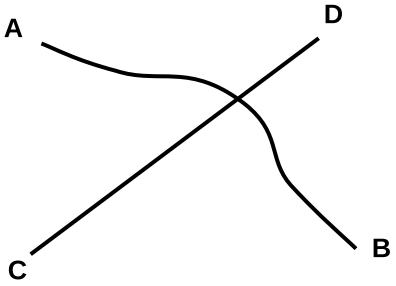


Gestalt law of good form

Fig. 11 (Anderson, 1996, p. 43)

A stimulus will be organised into a figure as well as possible. Here, "good" means symmetrical, simple, and regular.

The figure appears to the eye as two overlapping circles, not a combination of several complicated shapes.

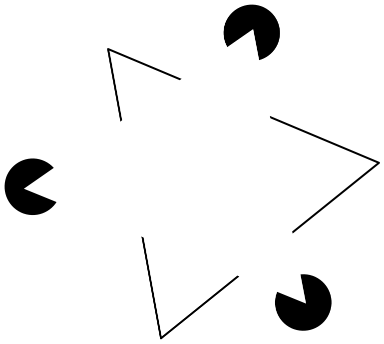


Gestalt law of continuity

Fig. 12 (Anderson, 1996, p. 43)

Human perception completes visual patterns. There is a tendency to continue contours whenever the elements of the pattern establish an implied direction.

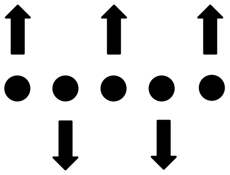
In the example, people tend to draw a good continuous line.



Gestalt law of closure

Fig. 13 (Matlin & Foley, 1997, p. 152)

We tend to enclose a space by completing a contour and ignoring gaps. We may experience elements we do not perceive through sensation, which lead to the perception of a regular figure.



Gestalt law of common fate

Fig. 14 (Matlin & Foley, 1997, p. 130)

When objects move in the same direction, we tend to see them as a unit.

In the example, when the dots 1, 3, and 5 move upwards and dots 2 and 4 move downwards at the same time, the dots moving in the same direction are perceived as a group

4.2 Usability engineering

Usability engineering applies standards, empirical methods and operational definitions of user requirements in the design and evaluation of products. Use of the resulting products should as intuitive as possible; taking the minimum of time to learn their operation and to accomplish the desired task. McLaughlin (1987) concludes: "*The main consideration is reducing the likelihood that the end user will not or cannot effectively use the system. The process begins with user analysis to produce cognitive and work style models, and task analysis to produce user work functions and scenarios. Feedback is rapid and productive, and user effectiveness can be measured and observed before the system is built and fielded*" (p. 183).

By integrating the user in the design process, it is possible to identify any "*… significant gap[s] between the use situation as envisaged by the designer and that which actually exists in practice*." (Hale, Kirwan and Kjellén, 2007, p. 314). According to Wilpert (2007), the existence of such 'perception gaps' can be explained by designers' tendency to overestimate users' technical know-how.

A user-centred design should result in greater satisfaction on the part of the operator and reduce development costs (Urbas, Steffens, Beu & Jacob, 2005). However, despite the competitive advantage offered by usability engineering, it is still widely ignored in industry. In most instances, it is still technical feasibility that dictates the division of functions between human beings and machine, with the user only being involved in the final testing phase. Frequently, difficulties in learning how to operate a machine or common operating errors are only identified at this late stage, by which time it is often too late to make the necessary changes.

There are a number of questions which should be addressed at the start of the design process:

- Is the information presented in a way that is adequate to the task?
- Can the design be understood intuitively?
- Is the HMI equal to the expectations of the operator?
- How error tolerant is the system?
- Can the HMI be adapted to several user groups?
- Does the HMI support learning how to run the system?

The usability engineering process can be separated into four iterative phases: (1) analysis phase (concerning working system, work, target groups, identification of user demands), (2) concept phase (concept of use with respect to different user target groups and decision on system functionality), (3) development phase (development of prototype and system integration), (4) implementation phase (pilot installation of prototype, industrial engineering).

Users are involved in all stages and take an active part in the evaluation processes under the moderation of usability engineers. The integration of operators in the design process right from the start avoids iterative loops which commonly occur when the testing of HMI is left until the final stages of the process. Involvement of operators in the evaluation process can be achieved through the use of surveys; by direct observation of the user at his workplace; through structured discussions; by participation of the user in design workshops; or through feedback concerning prototypes or products in usability tests. (Koller, Beu & Burmester, 2004 in Luczak, Schmidt, Koller).

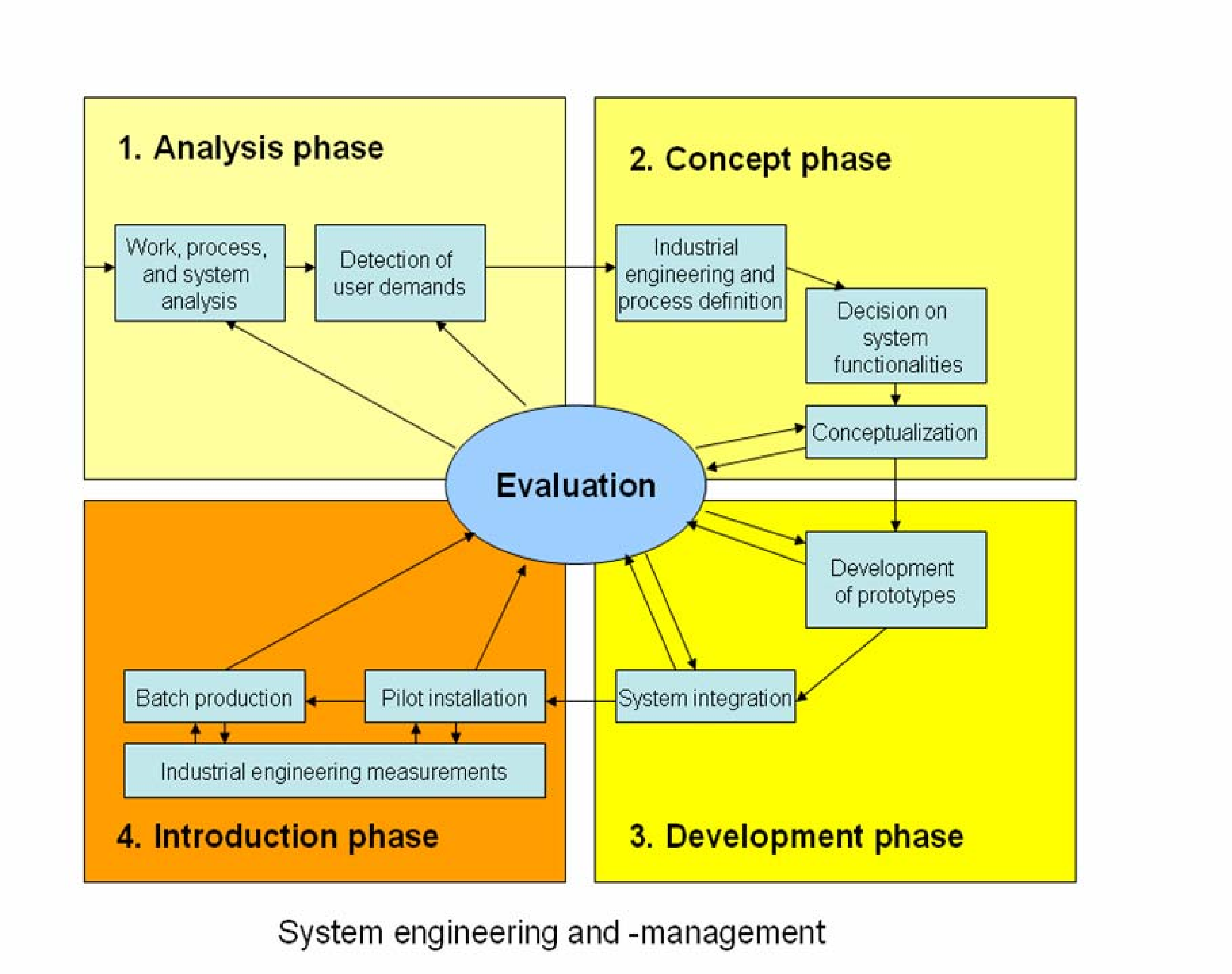


Fig. 15: Process model “Usability Engineering” (Sarodnick & Brau, 2006, p. 85), Copyright by Hogrefe, Verlag Hans Huber Bern 2008

Analysis phase:

It is important to ensure that the interface is properly adapted to the task and to the conditions in which the task will be performed. During the analysis phase, the following types of questions must be addressed: Which tasks occur and how often? How are the tasks managed? Who performs them? In what time do they need to be accomplished? What skills are necessary? How are the tasks linked together? What qualifications and qualities do the people performing the tasks have? How do they work together? What hardware and software do they use? What are the working conditions? It is essential to gather information on requirements directly from the operators as they are experts in their work and their ideas may well prevent less than optimal developments (Sarodnick & Brau, 2006).

Concept phase:

Based on the results of the analysis phase, an interdisciplinary team made up of usability experts, industrial engineers, designers and experts involved in organisational development create a concept for the design of the HMI. This phase must consider, for example whether the technical innovations will lead to changes in the existing working process. An important step is the allocation of tasks to humans and to machines, which implies an assessment of the functionalities within the system. The concept must be evaluated and the new system may be adapted (Sarodnick & Brau, 2006).

Development phase:

Development involves constructing a prototype and evaluating it. This phase gives importance not only to functionality, but also to aesthetic design. Designs of HMI should not only be usable but also permit “joy of use” (Sarodnick & Brau, 2006).

Implementation phase:

The implementation of the HMI is first of all carried out within a limited set of users and should involve evaluation measures. If amendments are necessary, a loop back to the development phase should follow. If the implementation is judged to be successful, the implementation can be enlarged, but should be accompanied by further evaluation measures. During the whole implementation process, any worries or fears expressed by users should be taken into account so as to help avoid acceptance problems (Sarodnick & Brau, 2006).

4.3 Virtual Reality

Innovations that support users in their interactions with machines offer gains not only in efficiency and productivity, but also in users’ performance and in reduction of health and safety risks. Virtual reality (VR) technology makes it possible to enrich the real (working) context with computer-simulated environments or objects to different degrees. At one end of the spectrum, VR depicts a world that is entirely computer-generated, which the user perceives as such and can interact with in real time. At the other end, “augmented reality” enriches the real world with computer-generated information. In between the two is “Mixed reality”, which describes the whole continuum between the real world and the virtual world. (Schmidt, Wiedenmaier, Oehme, Luczak, 2004 in Luczak, Schmidt, Koller).

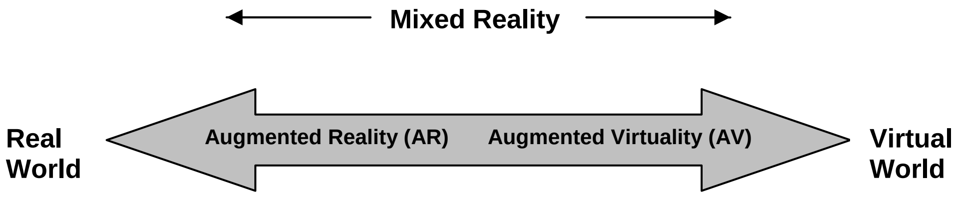


Fig. 16: ‘Virtuality Continuum’ (VC) according to Milgram, Takemura, Utsumi and Kishino (1994)

Invented in the 1960s, VR-technology began to be applied in industry in the mid 1990s and is now applied in many fields e.g. medicine, engineering, industry, architecture, research and education. Its uses include design conception, practical training, maintenance and better understanding of occupational accidents (Ciccotelli & Marsot, 2005).

VR is characterised by two essential aspects: the fact that users not only perceive a computer-generated world, but that they also interact in this world in real time. Below are some examples of how VR can improve health and safety when it is applied to HMI:

- Ciccotelli and Marsot (2005) mention that iterative design processes can be simplified by using VR simulations to conduct user tests, thereby reducing or eliminating altogether the need for extensive, time-consuming prototypes.
- Määttä (2003) applied VR technology to machinery safety analysis by combining a virtual environment with a ‘participative ergonomics approach’, work safety analysis methods and task analysis methods. Määttä used this approach to analyse hazards during modernisation projects in different plants (e.g. hot steel storage plant, steel converter plant) and demonstrated the usefulness of VR technology in safety analysis.
- Weiner (2007) describes a virtual safety training program for excavator drivers, which allows them to undertake practical exercises in realistic conditions, but without the real-world safety risks. The training takes place in a reproduction of an excavator driver’s cab, using VR glasses to generate a virtual landscape while drivers use steering-wheel, accelerator, and brake pedal to operate the virtual excavator. Different tasks have to be accomplished, such as driving in areas without obstacles, driving on slopes, driving around obstacles, driving in different weather conditions and on different terrain.
- VR is also frequently used to train nuclear power plant staff, e.g. reactor operators, allowing them to experience realistic simulations of critical situations (Markidis & Rizwan, 2006).

There are still technological limits in creating high-fidelity VR images, especially concerning multimodal interaction beyond visual and auditory interaction. Nevertheless, VR technology is an area of HMI that is evolving rapidly and has the potential to be of great relevance to OSH.

4.4 Augmented Reality (AR)

Augmented reality (AR) describes an environment that includes both virtual and real-world elements. The user’s field of vision is enriched with computer-generated virtual objects in order to make additional product or process information available in the context of the perceived reality (Schmidt, Wiedenmaier, Oehme, and Luczak, 2004 in Luczak, Schmidt, and Koller). Typically, goggles or screens are used to superimpose computer-generated information and images on the view of the real world. Unlike VR, AR allows the user to interact with real-world subjects and objects and is less likely to give false tactile or proprioceptive feedback.

Azuma (1997) identified the following areas of application for AR: medicine, manufacturing and repair, annotation and visualisation, robot path planning, entertainment, and military aircraft. Schmidt, Wiedenmaier, Oehme, and Luczak (2004 in Luczak, Schmidt, Koller) mention that AR is also used in areas such as simulation of real estate in architecture or enrichment of the interior design with virtual objects and in development, production and service (for instance maintenance).

Sakas (2002) described the uses of AR in medicine, such as combined with computer tomography, for training systems, in 3D angiography and in 3D ultrasound. He noted that with increasing computer power and falling prices, this technology has become widespread in medicine today.

(Ong, Yuan and Nee, 2007) describe the uses of AR in simulating and improving the design of manufacturing processes.

Head-up displays for civilian pilots have been shown by Bandow (2006) to reduce stress, particularly during abnormal flight situations and the final approach, and also to improve situational awareness.

AR can facilitate tasks such as maintenance or assembly by projecting operating instructions, labels of system parts, or construction plans on top of the view of the real system.

The application of AR-systems depends on the context, such that additional information provided by AR is adapted to the job. The aim is to provide the user with as much support as possible, while ensuring that the operation of AR-system itself demands minimal attention.

An example of the type of user support that can be provided by AR is the context navigator developed by the ARVIKA human-technique-interaction project supported by the German Federal Ministry for Education and Research. “Context objects” are detected, such as the position of the user, his line of vision, his working processes, tasks accomplished and those yet to be undertaken. Based on this information, the context manager provides the user with data relevant to the task and situation. The user can select which of the context objects to view in the mobile AR-system. A service technician, for example, could view layout plans or pipe plans for the job in hand. (Quaet-Faslem, Womann & Beu, 2004 in Luczak, Schmidt, Koller).

4.5 Instruction manuals

Correct installation and operation of technological products is critical for health and safety. In practice, however, many accidents are caused by faulty installation or operation as a consequence of either not reading or failing to understand the relevant instructions (You, Young, Zimmermann, Ekrut, Kumar & Lee, 2001; Wiese, Sauer & Rüttinger, 2004). The importance of providing adequate instructions is reflected in the provisions of the machinery Directive 98/37/EC and ISO standards relating to technical product documentation

Reinert, Brun & Flaspöler (2007) identified success factors in communicating safety-related information as part of a project to make more users read and understand operating instructions. The study “Complex machinery needs simple explanation” concluded that the best concept for presenting safety-related information consists of a multimedia package for operating instructions comprising a video and poster as well as a paper version of the operating instructions.

A video gives elementary information and can raise users’ awareness at the outset using appropriate animation. Posters are able to explain the key information at a glance and can be placed where the work is being carried out. The main aim of the poster and video is to encourage users to extend their knowledge by referring to the written operating instructions. Several measures were identified that ensure that the information is communicated as effectively as possible:

- Visual aids providing an overview of the most important information can integrate simulations, illustrations, comics, photos, tables, coloured text, etc.
- The text must be readable. It should be simple, with logical sentences using the active rather than passive form and structured in short informative chapters.
- Contents tables and indexes allow the user to find specific information at a glance.
- Checklists make text more user-friendly and help guide the users through the necessary steps and let them see whether they have worked adequately.
- Instructions for correct operation should be presented sentence by sentence and warnings should be emphasised in the text.
- Symbols, terminology and units of measurement should be used consistently (as defined in available standards) and tables should describe them further. Formulae and concepts should be explained. Glossaries should be used to explain key terminology.
- Special attention must be paid to ensure that translations into other languages are adequate. The use of cartoons assists understanding for all readers.
- Software help functions and interactive features enable the user to work efficiently with the system.
- Quizzes, cross-words, or other games may be used to evaluate the user’ knowledge.

Similar success criteria can be found in standards and should be fulfilled when designing operating instructions for products or machines. In practice, however, many examples of operating instructions fail to meet even the minimum requirements specified in the norms.

5 Standards relating to HMI

5.1 The role of standards in HMI design

Standards play an important part in the application of design principles, but their application is also limited. Firstly, the pace at which technology develops means that legislation, standards and guidelines are always lagging behind to some extent. Secondly, awareness concerning standards and guidelines relevant to HMI is relatively low. This may be due to the tremendous amount of information given in standards, which may be seen as too much of a challenge for many – especially smaller - enterprises.

A number of standards are relevant to HMI and they are described below. International standards ISO 9241[10] and ISO 13407[11] cover work with computers and other interactive systems and serve to illustrate the multidisciplinary approach that is needed to ensure effective HMI. These standards combine knowledge from the fields of software engineering, work science and cognitive ergonomics.

ISO 9241 deals with various aspects of human computer interaction (HCI). Originally entitled "Ergonomic requirements for office work with visual display terminals (VDTs)", its field of application has been extended and it is now called "Ergonomics of Human System Interaction".

Following the general introduction in Part 1 of ISO 9241, Part 2 provides guidance on task requirements and task design for working with computer systems; Parts 3–9 deal with physical characteristics of computer equipment like visual display requirements, keyboard requirements or workstation layout and postural requirements; and Parts 11 to 19 and 110 deal with usability aspects of interactive systems. Part 110 is of particular relevance to HMI in that it specifies general ergonomic design principles without reference to particular situations of use or applications. Intended to serve as a general framework for the analysis, design and evaluation of interactive systems, it is based on seven general principles that apply to the interaction of people and information systems:

1. Suitability for the task – the dialogue or the product should be suitable for the user's particular task and specific skill level.
2. Self-descriptiveness – the dialogue should be transparent at any step in the interaction.
3. Controllability – the user should be able to control the steps and the speed of the interaction.
4. Conformity with user expectations - the dialogue should be consistent with the user's intuition or expertise.
5. Error tolerance - the dialogue should anticipate user actions and compensate or "forgive" possible mistakes by the user.
6. Suitability for individualisation – the dialogue should be able to be customised to suit the individual user or specific groups of users.
7. Suitability for learning – the dialogue should support or ease its learning.

These principles are often used as the basis for evaluation of interactive systems. Furthermore, ISO 9241 (part 11) provides a widely used definition of usability: "*The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.*"

Whereas ISO 9241 covers ergonomic requirements, ISO 13407 deals with the design process of interactive systems. In providing guidance for the complete life cycle of a product, it gives reasons for the application of a human-centred design process; provides references to relevant standards; and advises on planning and management.

Depending on the context, there are a great number of standards that are also relevant to HMI. Nachreiner et al. (2006), for example, refer to standards relevant to the design of process control systems, which include EN 641-1[12] and ISO 11064:5[13].

---

[10] ISO 9241:1998 Ergonomic requirements for office work with visual display terminals (VDTs)

[11] ISO 13407:1999 Human-centred design processes for interactive systems

[12] EN 614-1:2006 Safety of machinery. Ergonomic design principles. Terminology and general principles

[13] ISO 11064-5:2008 Ergonomic design of control centres -- Part 5: Displays and controls

5.2 Overview of European and international standards relating to HMI[14]

EN standards are ratified by one of the three major European committees for standardisation (Comité Européen de Normalisation/European Committee for Standardisation (CEN)); Comité Européen de Normalisation Electrotechnique/European Committee for Electrotechnical Standardisation (CENELEC) or European Telecommunications Standards Institute (ETSI)).

EN ISO standards are developed by one of the three major European committees for standardisation listed above and the International Organisation for Standardisation (ISO).

ISO standards are ratified by the International Organisation for Standardisation (ISO) which is composed of national standards bodies from over 75 countries.

ISO/IEC standards are worked out by a joint committee of the International Organisation for Standardisation (ISO) and the International Electrotechnical Commission (IEC) (JTC1).

IEC standards are developed by the International Electrotechnical Commission (IEC).

Abbreviation	Name	Parts
EN standards ratified by CEN, CENELEC, or ETSI:		
EN 349	Safety of machinery; minimum gaps to avoid crushing of parts of the human body	
EN 547	Safety of machinery – Human body measurements	Part 1: Principles for determining the dimensions required for openings for whole body access into machinery Part 2: Principles for determining the dimensions required for access openings Part 3: Anthropometric data
EN 614	Safety of machinery – Ergonomic design principles	Part 1: Terminology and general principles Part 2: Interactions between the design of machinery and work tasks
EN 894	Safety of machinery – Ergonomic requirements for the design of displays and control actuators	Part 1: General principles for human interactions with displays and control actuators Part 2: Displays Part 3: Control actuators Part 4: Location and arrangement of displays and control actuators
EN 1005	Safety of machinery – Human physical performance	Part 1: Terms and definitions Part 2: Manual handling of machinery and component parts of machinery Part 3: Recommended force limits for machinery operation Part 4: Evaluation of working postures and movements in relation to machinery Part 5: Risk assessment for repetitive handling at high frequency
EN 13861	Safety of machinery – Guidance for the application of ergonomics standards in the design of machinery	
EN 60447	Basic and safety principles for man-machine interface, marking and identification – Actuating principles	

---

[14] The following list of standards related to HMI was compiled using Perinorm, the leading bibliographic database of national, European and international standards. Complementary information was taken from the standards publication house Beuth Verlag and sources such as Usability Net.

EN ISO standards are developed by the by CEN, CENELEC, or ETSI and the International Organisation for Standardisation (ISO)		
EN ISO 6385	Ergonomic principles in the design of work systems	
EN ISO 9241 (EN ISO 9241-117 is intended to revise and replace ISO 16071. EN ISO 9241-10 is revised by EN ISO 9241-110)	Ergonomics of human-system interaction (earlier called: Ergonomic requirements for office work with visual display terminals (VDTs))	Part 1: General introduction Part 2: Guidance on task requirements Part 3: Visual display requirements Part 4: Keyboard requirements for visual display terminals Part 5: Workstation layout and postural requirements Part 6: Guidance on the work environment Part 7: Requirements for display with reflections Part 8: Requirements for displayed colours Part 9: Requirements for non-keyboard input devices Part 11: Guidance on usability Part 12: Presentation of information Part 13: User guidance Part 14: Menu dialogues Part 15: Command dialogues Part 16: Direct manipulation dialogues Part 17: Form filling dialogues Part 110: Dialogue principles Part 117: Guidance on software accessibility
EN ISO 10075	Ergonomic principles related to mental workload	Part 1: General terms and definitions Part 2: Design principles Part 3: Principles and methods for measuring and assessing mental workload
EN ISO 11064	Ergonomic design of control centres	Part 1: Principles for the design of control centres Part 2: Principles for the arrangement of control suites Part 3: Control room layout Part 4: Layout and dimensions of workstations Part 5: Displays and controls Part 6: Environmental requirements for control centres Part 7: Principles for the evaluation of control centres
EN ISO 12100	Safety of machinery – Basic concepts, general principles for design	Part 1: Basic terminology, methodology Part 2: Technical principles
EN ISO 13406	Ergonomic requirements for work with visual display based on flat panels	Part 1: Introduction Part 2: Ergonomic requirements for flat panel displays
EN ISO 13407	Human-centred design processes for interactive systems	
EN ISO 14738	Safety of machinery – Anthropometric requirements for the design of workstations at machinery	
EN ISO 14915	Software ergonomics for multimedia user interfaces	Part 1: Design principles and framework Part 2: Multimedia navigation and control Part 3: Media selection and combination

ISO standards ratified by the International Organisation for Standardisation (ISO)		
ISO 16071 (The standard will be replaced by ISO 9241-171)	Guidance on accessibility for human-computer interfaces	
ISO 16982	Ergonomics of human-system interaction – Usability methods supporting human-centred design	
ISO 18529	Ergonomics of human-system interaction – Human-centred lifecycle process descriptions	
ISO 20282		Part 1: Design requirements for context of use and user characteristics
ISO 9127		
ISO/IEC standards developed by a joint committee of ISO and IEC (JTC1):		
ISO/IEC 9126	Software engineering – Product quality	Part 1: Quality model Part 2: External metrics Part 3: Internal metrics Part 4: Quality in use of metrics
ISO/IEC 10741	Information technology – User system interfaces	Part 1: Cursor control for text editing
ISO/IEC 11581	Information technology - User system interfaces and symbols - Icon symbols and functions	Part 1: Icons – General Part 2: Object icons Part 3: Pointer icons Part 5: Tool icons Part 6: Action icons
ISO/IEC 14598	Information technology – Software product evaluation	Part 1: General overview Part 2: Planning and management Part 3: Process for developers Part 4: Process for acquirers Part 5: Process for evaluators Part 6: Documentation of evaluation modules
ISO/IEC 14754	Information technology – Pen-based interfaces – Common gestures for text editing with pen-based systems	
ISO/IEC 15504		Improvement and process capability determination
ISO/IEC 15910	Information technology – Software user documentation process	
ISO/IEC 18019	Software and system engineering – Guidelines for the design and preparation of user documentation for application software	
ISO/IEC 18021	Information technology – User interfaces for mobile tools for management of database communications in a client-server model	
IEC standards developed by the IEC		
IEC 61997	Guidelines for the user interface in multimedia equipment for general purpose use	

Technical Reports (ISO TR) by the International Organisation for Standardisation can be regarded as informative documents containing information which is different from information given in normative standards. Technical Specifications (ISO TS) of the International Organisation for Standardisation are normative documents that may later be revised and published as a standard.

5.3 Directives

Two European directives of particular relevance to usability – the display screen directive and the machinery directive – have been implemented through national legislation in each Member States.

Abbreviation	Name	Contents
Directive 90/270/EEC	Display Screen Equipment Directive	Minimum ergonomic requirements for workstation equipment and the environment / Principles of software ergonomics
Directive 98/37/ EC	Machinery Directive	Health and safety requirements for machinery (e.g. user-friendly interactive software)

6 Conclusion

As science and technology advance, we find increasingly complex machines, as well as an evermore widespread automation in the workplace. The HMI governs the flow of information from the machine to the user (in terms of displays, warning sounds, etc.) and from the user to the machine (in terms of input or control devices such as keyboards, switches, levers, etc.). Its design has important consequences for health and safety at work because of the growing potential for accidents and ill health for machine operators. Increasing complexity affects not only the way operators use a machine, but also leads to more automation, which in turn impacts on the way work is organised.

The majority of machine users work in SMEs; mostly in manufacturing, although significant numbers also work with machines in construction, communication and transport, and agriculture. No age group is more or less likely to work with machines, but users typically have lower than average skill level and work full time. Compared with the general working population, machine workers are more likely to carry out repetitive work, to work standing upright and to carry heavy loads. As might be expected, they are also more exposed to poor environmental conditions such as fumes and dust, heat or cold, noise and dangerous substances and are more likely to have to wear personal protective equipment. Finally, machine workers have significantly less control over their work organisation, breaks or amount of work than other workers.

Deficiencies in the HMI present both a psychosocial risk and an accident risk. In the first case, stress can result from cognitive overload or under-load and in the second, occupational accidents can result from operating errors. Additionally, human error can also result in major accidents; typically in high-risk industries, such as nuclear, oil, gas, etc.

A machine user can suffer cognitive overload if, for example, too much information is given too quickly, or it is not readily understandable, or it is ambiguous, or conflicts with other information or is unexpected. Cognitive under-load, in contrast, tends to arise where automation has taken the content out of a person’s job so that it lacks interest and is not stimulating. An example might be monitoring of a highly automated manufacturing process.

Poor HMI can lead to occupational accidents in a number of ways. The most common cause is an operational error arising out of, for example, failure to understand or to act upon the information provided by the machine, or inability to control the machine correctly, for example because of an input error. Many accidents, however, can also be attributed to the HMI not being adapted to non-routine operation, such as during maintenance or repair. Finally, a badly designed HMI can also encourage inappropriate actions, such as taking shortcuts or making modifications to the machine, such as bypassing safety devices, which often lead to accidents.

The main impact of widespread computerisation is the possibility of providing the operator with very high levels of information and functionality. In many cases, however, designers are not aware of the relevant design principles and tend to overload the user, who then finds it difficult to interpret information and control the machine. A further consequence of this tendency is the need for longer training and more detailed instructions.

New technology, when introduced poorly, carries the risk of increasing operators’ mental workload and also of reducing their degree of task control. Furthermore, the resulting changes in work organisation demand a holistic, systems-based approach that optimises allocation of tasks and the working environment in order to reach an ergonomic workplace design. Also essential to this approach is the provision of proper information and training and the involvement of workers in the change. A failure to take these measures increases the risk of have negative health effects such as stress and is likely to result in an over-reliance on automated safety systems.

It must be borne in mind that technology offers the potential to substantially improve HMI by, for example, providing better information and feedback or by facilitating control. However, in order to realise the potential, the design principles described in this report need to be applied. It is generally agreed that the potential offered by new technology is realised only to a small extent. Some differences, however, exist between various branches of industry, depending on their familiarity with complex HMI.

The largest scope for improvement is in the consideration of workers and their needs in the design process. The focus on the human factor needs to be increased to take account of physical aspects (such as perceptual processes) and psychological aspects (such as cognitive processes). The design process should serve to reinforce human factor potentials and limitations. Input from users to the design process is essential and can be based on testing (e.g. using prototypes or mock-ups) or on the experience of existing users of similar technology (if available).

Moreover, achievement of a good HMI does not end with an adequate design. The implementation of the new technology and its combination with existing machines and installations at the workplace is a vital, if often overlooked, step. Typically, operationalisation is too late, too little, or does not happen at all. Correct operationalisation is also important when technology is transferred from one sector to another or when integrating and adapting complex automated processes to the business context or to another cultural background.

An important obstacle to the fulfilment of technology's potential to improve HMI is the pace of development and pressure to deliver technical solutions quickly, which limits the time available for design and testing.

Workers often encounter difficulties adapting to technological change, particularly if it is done quickly. Therefore, it is important to implement changes to machines, technologies, or processes in a step-wise manner, so as to avoid overloading workers. Resistance to change can also come from the enterprise itself; possible because of a perception that the benefits of the new technology do not justify the costs of purchase and installation. Off-the-shelf production can be of poor fit, but customised production is expensive and probably not so reliable, as there can be compatibility problems between items of equipment and systems. The engineering of machine controls is often outsourced with the result that development of HMI is given less importance. The cost of testing also means that usability is often evaluated only to the extent of ensuring there are no potentially dangerous features.

Last but not least, standards and guidelines provide an important framework covering design of HMI, aspects of the design process and accompanying material, such as user instructions. Unfortunately, the applications of standards and guidelines low in practice and their relevance is sometimes limited by the pace of technical development.

6.1 Recommendations for research

There is still much basic research that needs to be carried out and the results of existing research need to be put into practice more effectively. The following non-prioritised list identifies some of the most important priorities for HMI-related research:

- Field studies are needed so that organisational and environmental factors that are difficult to replicate under laboratory conditions can be properly taken into account.
- Accident investigation data needs to be improved and harmonised so as to enable better analysis and identification of causation.
- Usability testing should include evaluation of HMI under emergency situations, rather than just normal operation, as operators' actions can be very different in these circumstances.
- More research is needed that focuses on the needs of specific worker groups:
  - New technology can facilitate access to the labour market for disabled workers
  - More account needs to be taken of maintenance workers, such as ensuring that menu navigations specific to maintenance work are always included and are of high quality.
  - Migrant workers are more likely to have difficulties in understanding instructions, written commands, etc. and may have different expectations and levels of experience.
- Jobs involving complex tasks and time pressure need further investigation as part of a greater research effort into cognitive ergonomics, work motivation and well-being at work.
- Research into the importance of user-friendliness is needed to avoid systems becoming 'black boxes', with operators not understanding how they work.
- Cost-benefit analyses need to demonstrate the cost effectiveness of ensuring an optimal HMI as regards increased productivity and decreased implementation costs.
- Findings from different studies need to be combined to a greater extent and collaboration must increase between groups such as developers, users and suppliers.
- Research needs to be put into practice more effectively.

References

Anderson, J. R. (1996). Kognitive Psychologie. Spektrum Akademischer Verlag: Heidelberg.

Azuma, R. (1997). A survey of augmented reality. Presence: Teleoperators and Virtual Environments, 6 (4), 355-385.

Backström, T. & Döös, M.: The technical genesis of machine failures leading to occupational accidents. International Journal of Industrial Ergonomics, Vol. 19(5), pp. 361-376, 1997.

Backström, T. & Harms-Ringdahl, L.: A statistical study of control systems and accidents at work. Journal of Occupational Accidents, Vol. 6, pp. 201-210, 1984.

Backström, T., Döös, M.: A comparative study of occupational accidents in industries with advanced manufacturing technology. International Journal of Human Factors in Manufacturing, Vol. 5 (3), pp. 267-282, 1995

Bainbridge, L.: Ironies of Automation. In Rasmussen, J., Duncan, K., Leplat, J. (Hrsg.): New Technology and Human Error. N.Y.: Wiley 1987.

Bandow, D. (2006). Head-up-Guidance-Systeme und Mensch-Maschine-Interaktion. Zeitschrift für Arbeitswissenschaft 60 (2), 107-121.

Baumann, K. & Lanz, H.: Mensch-Maschine-Schnittstellen elektronischer Geräte. Leitfaden für Design und Schaltungstechnik. Berlin-Heidelberg: Springer, 1998.

Becker, F. Leistungsfähige Systembausteine zur Erfüllung der Kommunikationsanforderungen. Glückauf, Nr. 11, Essen: VGE-Verlag GmbH, 2006.

Beer, B.: Gestaltung der Schnittstelle Mensch/Anlage/Prozess im Rahmen von Anlagenplanungen-Sicherheitsbezogene Anforderungen und Untersuchungsergebnisse. Zeitschrift für Arbeitswissenschaft, 55 (4), pp. 214-215, 2001.

Bubb, H.: Menschliche Zuverlässigkeit, Sicherheit und Risikobeurteilung. Zeitschrift für Arbeitswissenschaft, Köln (20NF), S. 8-13, 1994.

Bundesministerium für Wirtschaft und Arbeit (2001). Arbeitsunfälle mit Maschinen, Studie der Arbeitsinspektion. Wien. http://www.arbeitsinspektion.gv.at/NR/rdonlyres/6F647B66-AAD9-4263-93B7-A73AD215A1BF/0/masch_unfaelle.pdf

Carey, J.M.: Human factors in management in formation systems. Ablex Publishing Corporation: Norwood, New Jersey, 1998.

Charwat, J.: Lexikon der Mensch-Maschine-Kommunikation. München, Wien: Oldenbourg, 1992.

Ciccotelli, J. & Marsot, J. Réalité virtuelle et prévention. Apports et tendances. Hygiène et sécurité du travail – Cahiers de notes documentaires, 199, Points de repère – PR 17, 99-111, 2005.

Dahm, M.: Grundlagen der Mensch-Computer-Interaktion. Pearson Studium: München, 2006.

Ditchen, D., Ellegast, R.P., Herda, C., Hoehne-Hückstädt, U. Ergonomic intervention on musculoskeletal discomfort among crane operators at waste-to-energy-plants Contemporary Ergonomics 2005. S. 22-26, 5 Lit., 1 Tab., 3 Abb. Hrsg.: Bust, P.D.; McCabe, P.T. Taylor & Francis, London.

Döös, M. & Backström, T.: Production disturbances as an accident risk. In Kidd, P.T. & Karwowski, W. (Eds.): Advances in agile manufacturing. pp. 375-378. IOS Press, London 1994.

Döös, M., Backström, T. & Samuelsson, S.: Evaluation of a strategy. Preventing accidents with automated machinery through targeted and comprehensive investigations conducted by safety engineers. Safety Science, Vol. 17(3), pp. 187-206, 1994.

Döös, M., Backström, T. & Sundström-Frisk, C.: Human actions and errors in risk handling - an empirically grounded discussion of cognitive action-regulation levels. Safety Science, vol 42, pp. 185-204, 2004.

Dreher, K.: Der 12-Punkte Plan: HMI maßgeschneidert. Computer Automation, 10, 48-53, 2001.

Einarsson, S. (1999). Human error in high hazard systems: Do we treat the problem in an appropriate way? Journal of Risk Research, 2:2, 115-128.

Ellegast, R.P., Lesser, W., Herda, C., Hoehne-Hückstädt, U., Schwan, W. & Kraus, G. Physical workload at sewing workplaces - an ergonomic intervention study (IEA 2006. 16. World Congress on Ergonomics. 10.-14. Juli 2006, Maastricht/Niederlande - Vortrag. CD-ROM, 6 S., 10 Lit., 4 Tab., 3 Abb. Hrsg.: Pikaar, R.N.; Koningsveld, E.A.P.; Settels, P.J.M. Elsevier Ltd. 2006

EU-OSHA: Priorities for occupational safety and health research in the EU-25. Luxembourg: Office for Official Publications of the European Communities, 2005.

EU-OSHA: Expert forecast on emerging physical risks related to occupational safety and health. Luxembourg: Office for Official Publications of the European Communities, 2005.

Gerr F, Marcus M, Ensor C, Kleinbaum D, Cohen S, Edwards A, Gentry E, Ortiz DJ, Monteilh C. 2002. A Prospective Study of Computer Users: I. Study Design and Incidence of Musculoskeletal Symptoms and Disorders. Am J Ind Med 41(4):221-35.

Hale, A., Kirwan, B. & Kjellén, U. (2007). Safe by design: where are we now? Safety Science, 45, 305-327.

Haller, L.: Risikowahrnehmung und Risikoeinschätzung. Schriften zur Arbeits-, Betriebs- und Organisationspsychologie. Volume 3. Verlag Dr. Kovač. 2003.

Hoehne-Hückstädt, U.; Keller Chandra, S.; Ellegast, R.P.; Schäfer, P. Ergonomic requirements on input devices of information technology (Ergonomische Anforderungen an Eingabemittel der Informationstechnik) Contemporary Ergonomics 2007. S. 415-420, 22 Lit., 1 Tab. Hrsg.: Bust, P.D. Taylor & Francis, London. ISBN: 13 978-0-415-43638-0 (Sprache:GB)

Hollnagel, E.: Cognitive Reliability and Error Analysis Method (CREAM). Oxford: Elsevier Science Ltd. 1998.

HVBG (2006). Manipulation von Schutzeinrichtungen an Maschinen. Hauptverband der gewerblichen Berufsgenossenschaften. Sankt Augustin http://www.dguv.de/bgia/de/pub/rep/pdf/rep05/manipulation_schutzeinrichtungen/vorspann.pdf

Ipsos-MORI (1999) Employees Get 'It' Out Of Their Systems http://www.ipsos-mori.com/researchpublications/researcharchive/poll.aspx?oItemId=1900

Koller, F., Beu, A. & Burmester, M.: Benutzerzentrierter Gestaltungsprozess interaktiver Systeme. In Luczak, H., Schmidt, L. & Koller, F.: Benutzerzentrierte Gestaltung von Augmented Reality. pp. 15-26. VDI Verlag. Düsseldorf, 2004.

Määttä, T. (2003). Virtual environments in machinery safety analysis. VTT publications 516, Finland. http://www.vtt.fi/inf/pdf/publications/2003/P516.pdf

Marcus, M. & Gerr, F. (1996). Upper extremity musculoskeletal symptoms among female office workers: Associations with video display terminal use and occupational psychosocial stressors. American Journal of Industrial Medicine, 29(2), 161-170.

Markidis, S. & Rizwan, U. A virtual control room with an embedded, interactive nuclear reactor simulator. 5th International Topical Meeting on Nuclear Plant Instrumentation Controls, and Human-machine Interface Technology (NPIC and HMIT 2006), vol. 2006, 675-679.

Matlin, M. W. & Foley, H. J. (1997). Sensation and Perception. Allyn & Bacon: Old Tappan, NJ.

Mattila, M. & Kiviniitty, J.: Job characteristics and occupational safety of manufacturing jobs at different levels of automation. International Journal of Human Factors in Manufacturing, Vol. 3 (3), pp. 243-252, 1993.

Mattila, M., Tallberg, T., Vannas, V. & Kivistö-Rahnasto, J.: Fatalities at advanced machines and dangerous incidents at FMS implementations. International Journal of Human Factors in Manufacturing, Vol. 5 (3), pp. 237-250, 1995.

McLaughlin, L. L.: User engineering: a new look at system engineering. First Annual Workshop on Space Operations Automation and Robotics (SOAR '87)., Houston, TX, NASA Conference Publication, n 2491, pp. 183-189, 1987.

Milgram, Paul; H. Takemura, A. Utsumi, F. Kishino (1994). "Augmented Reality: A class of displays on the reality-virtuality continuum" (pdf). Proceedings of Telemanipulator and Telepresence Technologies: 2351-34.

Miller, D. & Swain, A.: Human Error and Human Reliability. In Salvendy, G. (Hrsg.): Handbook of Human Factors and Ergonomics. N. Y.: Wiley, 1986.

Montenegro, S.: Sichere und fehlertolerante Steuerungen. Entwicklung sicherheitsrelevanter Systeme. Hanser. München, Wien, 1999.

Nachreiner, F., Nickel P and Meyer I. (2006). Human factors in process control systems: The design of human–machine interfaces. Safety Science, vol. 44, 2006, 5-26.

Oberhuber, N. Mensch gegen Maschine, DIE ZEIT 16.09.2004 Nr.39 http://images.zeit.de/text/2004/39/Computerfrust

Ong S. K., Yuan M. L. & Nee, A. Y. C. (2007). Augmented reality applications in manufacturing: a survey. International Journal of Production Research, 1-36.

Park, S. P.: Human Error. In G. Slavendy (Hrsg.): Handbook of Human Factors and Ergonomics. N. Y.: Wiley, 1997.

Quaet-Faslem, P., Womann, G. & Beu, A.: Gestaltung von Benutzeroberflächen für AR-Systeme. In Luczak, H., Schmidt, L. & Koller, F.: Benutzerzentrierte Gestaltung von Augmented Reality. pp. 40-54. VDI Verlag. Düsseldorf, 2004.

Reason, J.: A systems approach to organisational error. Ergonomics, Vol. 38(8), S. 1708-1721, 1995.

Reason, J.: Human error. Cambridge, MA: Cambridge University Press, 1990.

Reinert, D., Brun, E. & Flaspöler, E.: Complex machinery needs simple explanation. Safety Science, 45, 579-589, 2007.

Reuth, R. K.-A.: Simulationsgestützte Bewertung des Einflusses menschlicher Fehler in Autonomen Produktionszellen. Shaker Verlag. Aachen, 2003.

Sakas, G. (2002) Trends in medical imaging: from 2Dto 3D. Computers & Graphics, 26, 577–587.

Sarodnick, F. & Brau, H.: Methoden der Usability Evaluation. Wissenschaftliche Grundlagen und praktische Anwendung. Huber: Bern, 2006.

Schmersal: Harmonischer Dreiklang. Ergonomie und Sicherheit an der Schutztür steigern die Produktivität. Der Betriebsleiter, 4, 34-36, 2005.

Schmidt, L., Wiedenmaier, S., Oehme, O., & Luczak, H.: Augmented Reality als neue Form der Mensch-Technik-Interaktion. In Luczak, H., Schmidt, L. & Koller, F.: Benutzerzentrierte Gestaltung von Augmented Reality. pp. 1-14. VDI Verlag. Düsseldorf, 2004.

Skov, T., Borg, V. and Orhede, E. (1996). Psychosocial and physical risk factors for musculoskeletal disorders of the neck, shoulders, and lower back in sales-people. Occupational and Environmental Medicine, 53, 351-356.

Tutherow, G. K.: Operator Interface Evolution. In: B. G. Lipták. Instrument Engineers Handbook. Process Software and Digital Networks. Boca Roton, Florida: CRC Press, 2002.

Urbas, L., Steffens, C., Beu, A. & Jacob, F.: Der Nutzer steht im Mittelpunkt – Usability in der Industrie, Elektrotechnik und Automation, 9, 10-15, 2005.

Venus, M. (2005). Angewandte Psychologie in der Unfallverhütung. Sichere Arbeit, 5, 22-26.

Waters, R. M.: Use of standards to reduce human error. Safety Engineering and Risk Analysis, ASME, Proceedings of the 1994 International Mechanical Engineering Congress and Exposition, Nov 6-11 1994, Chicago, IL, vol. 2, pp. 161-166, 1994.

Weiner, M. (2007). Sicherheitstraining im virtuellen Bagger. Frauenhofer Magazin, 4, 20-21.

Wickens, C. D. & Hollands, J. G. (2000). Engineering Psychology and Human Performance (3rd ed.). Upper Saddle River, NJ: Prentice Hall.

Wiese, B., Sauer, J., Rüttinger, B. (2004). Consumers’ use of written product information. Ergonomics 47, 1180-1194.

Wilpert, B. (2007). Psychology and design processes. Safety Science, 45, 293-303.

Yee, K.-P. (2002). User Interaction Design for Secure Systems (ACM). In Proceedings of the 4th International Conference on Information and Communications Security (Lecture Notes in Computer Science 2513), 278–290, Springer-Verlag, 2002. http://zesty.ca/pubs/icics-2002-uidss.pdf

You, H., Young, R., Zimmermann, D., Ekrut, C., Kumar, A. & Lee; M. W.: A usability test for the operating manual of braidmagic. In: Proceedings of the Human Factors and Ergonomics Society. 45th Annual Meeting, pp. 679-701. 2001.

Zühlke, D. (2004). Use-ware-Engineering für technische Systeme. Heidelberg: Springer-Verlag.