ND 2256 - 205 - 06

APPLYING ERGONOMICS STANDARDS IN THE DESIGN OF WORK SYSTEMS: MEANS FOR IMPROVING THE SAFETY RELATED DESIGN QUALITY OF WORK SYSTEMS?

- Design
- Ergonomics
- Standardization

► *Friedhelm NACHREINER, Gesellschaft für Arbeits-, Wirtschafts- und Organisationspsychologische Forschung, Germany*

APPLYING ERGONOMICS STANDARDS IN THE DESIGN OF WORK SYSTEMS: MEANS FOR IMPROVING THE SAFETY RELATED DESIGN QUALITY OF WORK SYSTEMS?

☐ Design
☐ Ergonomics
☐ Standardization

► *Friedhelm NACHREINER, Gesellschaft für Arbeits-, Wirtschafts- und Organisationspsychologische Forschung, Germany*

As can be demonstrated by a number of examples from process control systems human factors are not well integrated and observed in the design of work systems, which must lead to dysfunctional consequences with regard to system effectiveness, efficiency, safety, and reliability as well as to operator performance and work load, which in turn will influence system performance. One of the reasons for this inadequate consideration of human factors in the design process might be a lack of acquaintance of designers, manufactures and customers with human factors and their uncertainty of what existing legal requirements to take human factors into account really mean. Another reason might be that designing safety into a system is often considered as a purely technical problem, with human factors playing only a minor role. However, as can be demonstrated, taking human factors into account improves operator and system performance. After presenting a short overview of standardization activities in the field of human factors problems with the application of these standards are discussed, especially with regard to testing compliance with these standards, and a brief account of ongoing activities to overcome these problems is presented, e.g. the revision of the basic standards with the possible inclusion of an evaluation standard. Applying human factors standards is considered a first step only for integrating human factors into the design process, which can make designers, manufacturers and customers aware of this field and the opportunities it has to offer to improve the design quality of work system with regard to system performance and safety.

As can easily be demonstrated by a great number of real world examples from different industries or service operations the design (and operation) of work systems, even that of rather complex work systems like process control systems of hazardous installations, is usually lacking adequate consideration of human factors (see Nachreiner et al., 2006, also for some examples). This applies to both the design of the operator work task(s) and activities, i.e. the human-machine-task-interface, as well as to the design of the work equipment and its interface to the operator, i.e. the human-machine-interaction-interface, independent of whether these interfaces have been implemented via hardware or software solutions, where with the latter we are dealing with generic technologies, allowing for a near to complete adaptation of the technical subsystem to the characteristics of the intended operator population. It is important to note that this sequence is essential, since system design cannot be effective when a well-designed interaction interface is applied to a badly designed task interface (priority of the task, Ulich, 2006).

This lack of consideration of human factors or ergonomics in adapting both interfaces to the operator, however, must inevitably increase the operators' (mental) work load, their work stress, work strain, and the impairing effects of such dysfunctional work strain, e.g. fatigue, monotony, or reduced vigilance (for a definition of these concepts see ISO 10075), and in the end the risk of human errors - and further, as a consequence, system failures, thus decreasing operational safety and system performance, reliability and availability - besides the risks imposed to the operators' health and well-being.

It would seem that this lack of consideration of human factors or ergonomics is - at least in part - due to the fact that the design of such work systems is still considered to be mainly (if not solely) a technical problem, with human operators coming in at the end of the design process, either as components for left-over tasks which are too expensive to be automated, i.e. for economic reasons, or because such systems, e.g. those with a high risk of hazards, would not be acceptable to the general public without any human operator - even if the control of the system lies completely within the machine in case of emergencies, as can be observed in the chemical or nuclear industries (Kappelmaier, 2002, Papin, 2006).

Besides such an intended or unintentional non-observation of human factors or ergonomics principles in the design of work systems another reason for the lack of application of these principles might be due to the lack of familiarity of the relevant groups, i.e. designers as well as customers, with ergonomics principles and/or the available evidence, since ergonomics does not seem to be an important or integral part in the professional training of designers - at least in Germany, where mechanical engineers or computer science professionals sometimes do not get an adequate education in human factors during their professional training. It can therefore not be expected that all or at least most designers (and customers) are fully aware of human factors principles, findings and their importance for the design (and operation) of work systems, which must result in suboptimal solutions.

If this is combined with the attitude of the general superiority of automated systems and a belief in their deterministic functioning and infallibility, this must result in systems where human operators and their characteristics are conceived as a nuisance and neglectable, as long as technical solutions would seem to warrant operational safety (e.g. Kappelmaier, 2002).

This then, if human operators are still left in such systems (and the question is why they are actually still there) must lead to systems which are far from optimal with respect to system effectiveness, efficiency, reliability and safety and the operators' unimpaired health and performance.

Since a number of industrial hazards has shown that this cannot be a successful strategy, at least as long as there are still human operators in the system fulfilling some kind of essential system function, it is mandatory that in the design (and operation) of work systems human factors or ergonomics deserve due consideration, in order to design a system that is compatible with human characteristics. If the design and operation of work systems still has to rely on human operators and their activities within such a system, it is inevitable to take these work (and worker) activities, their bases, control, regulations, their sequential and hierarchical order, as well as their limits, strengths and effects - on the system as well as on the operator - into account. In fact, if there is any human-machine interface, and this applies to the task and the interaction interface, these should be operator centred, since it should be kept in mind that the technical components of a work system offer a very wide range of opportunities for design (and design alternatives), especially with generic computer and software technologies, whereas the adaptability of the human is rather limited.

One of the problems to be solved then is to make designers (and their customers) aware of the importance of human factors, their role in the design process, i.e. incorporating ergonomics right from the beginning as an integral part - instead of a later (and thus usually more cost expensive) add-on or repair activity - and of the available and design-relevant ergonomics evidence.

Another problem to be considered in this context is that there are some legal obligations, at least within the EU, to take ergonomics adequately into account. So it is not just nice to have some ergonomics applied in the design of work systems, but in some cases a mandatory legal requirement. The European directives that are relevant here (e.g. the machinery directive, the framework directive, the VDU directive, or the SEVESO II directive) have been issued under two different perspectives (and articles of the European Treaties): specifying minimal health and safety requirements for workers in order to provide for comparable working and living conditions (article 137), and specifying requirements for the safety of machinery in order to provide against barriers to the free trade of goods within the EU (article 95).

Since such regulations, like their national implementations or other national legal regulations, usually provide general goals only (goal-oriented legislation) but no specific provisions about what must actually be done, they usually ask for compliance with the state of science and technology, and this includes in this case compliance with evidence-based principles and knowledge in the field of human factors or ergonomics. The question, however, is what these generally accepted principles and evidence are that have to be applied / observed in the design of work systems or its technical equipment. Since texts or handbooks would seem to be potentially biased by their authors' views and opinions, they are less well suited to fulfil this purpose. The question thus remains, where such evidence can be found.

On different national as well as the international and European levels the idea has thus been raised to develop national and/or preferably European or international ergonomics standards to provide designers (and their customers) and those responsible for the operation of work systems with the consensually agreed state of the art in order to specify any legal requirements concerning the implementation of ergonomics into the design of work systems.

ERGONOMICS STANDARDS

ISO TC 159 'Ergonomics' and CEN TC 122 'Ergonomics' (through their subcommittees and/or working groups) have produced a number of ergonomics standards for the design of work systems and their components, which could be readily applied in the design process and in the evaluation of design solutions, although a specific standard on the evaluation of the design of work systems is still missing. In total 22 International Standards have been developed (including Technical Reports), 54 European and International (EN ISO) parallel standards, 24 European standards (CEN standards), and a different number of national standards (e.g. 22 for the DIN, the German standardization body) in the field of ergonomics, with some more standards in related fields (e.g. safety of machinery, ICT, illumination, etc.) developed by different committees [status at the end of the year 2005].

International ergonomics Standards can be grouped into more basic, context free standards, like those dealing with the design of work systems (ISO 6385:2004) or special aspects, like mental work load (the ISO 10075 series) in a more general way, and context dependent or more specific standards, e.g. on requirements for office work (the ISO 9241 series) or control centres (ISO 11064 series). Whereas the more general standards apply to all kinds of work systems - and sometimes beyond, e.g. equipment for public or leisure use -, context dependent standards relate primarily to this context (e.g. office work or control centres), again sometimes with applications beyond this context, as is the case with the design of human-machine-dialogues, where the relevant principles have been specified in the first case for office environments (e.g. ISO 2941-10 on dialogue principles or ISO 9241-11 on usability of software products) but where experience has shown that some of these principles are – in principle, or after contextual adaptation, but not necessarily immediately and completely – also applicable to other contexts, e.g. process control environments (Nickel et al., 2004). An example here is the principle of error tolerance, which can be applied to process control systems only in a modified / adapted version, since e.g. an “undo” function cannot be realized in such real time systems. Thus warnings, blocking of control actions or predictive components will play a more important role in such a context than in the office context.

The current fields of standardization in ergonomics can best be outlined by a short description of the subcommittees of TC 159 and their scopes:

- Subcommittee (SC) 1 deals with fundamental principles or ergonomics, e.g. general terms and definitions, basic concepts, principles of system design, mental work load, or usability of everyday products.

- SC 3 deals with anthropometrics and biomechanics, thus with the classical physical design parameters for the design of work systems.

- SC 4, Human - System Interaction, deals with problems of the design of interactive, i.e. computer-supported, technical (sub-) systems, e.g. with the design philosophy for this kind of systems (ISO 13407), with the design of displays and control actuators, or more generally with the design of human-machine interaction interfaces, including principles of dialogue design. It is this SC which has developed and is updating the standards on office work with VDUs and those for control centres, although both work environments definitely call for more than just the human-machine dialogue, e.g. work station layout or the design of the work environment. However, it has been decided to deal with these aspects in their context of operation, leaving things together that belong together (e.g. all aspects of the design of control centres, from work station layout to dialogue design) in order to make it easier for designers (and management) to access interrelated information for the design and operation of such work systems within one series of standards.

- SC 5 deals with the ergonomics of the physical environment and has produced a great number of (generally as well as specifically) applicable International Standards on problems of the thermal environment, whereas basic lighting problems are dealt with in a CIE committee. SC 5 also deals with speech communication and danger signals.

As can be seen from this brief sketch of standardization activities there is already a substantial body of ergonomics standards which could readily be applied in the design and operation of work systems. Checking existing work systems against these standards immediately shows that the provisions in these standards have not been observed adequately in the design of some work systems. Violations concern both the design process (see e.g. Papin’s (2006) description of the design process in the nuclear industry in France, where ergonomics seems to enter rather late in the design process instead of being incorporated right from the beginning, as requested e.g. in ISO 6385, ISO 10075-2 or ISO 13407) as well as its results, and here again both the task and the interaction interface are concerned, with violations reaching from rather simply amendable violations of compatibility principles, e.g. a software generated scale on a VDU with decreasing values from left to right - where from an ergonomics perspective exactly the opposite, i.e. increasing values from left to right, would be required and which can easily be reprogrammed, to more severe and sometimes non amendable - at least not with an acceptable expenditure of resources - problems in the allocation of functions to the operator or the machine, e.g. the triggering of a complete plant shutdown.

Besides the available casual observations in the field (among others from the analysis of major hazards; see HSE, 1997 for an example) it would be interesting to systematically investigate what kinds of ergonomics recommendations have been violated and why this has been done. In fact, it would seem worth while to perform an evaluation of the ergonomics of existing process control systems, based on requirements specified in the relevant ergonomics standards, and to make an assessment of the impact which these violations of these provisions may have on operational safety, effectiveness, efficiency and operator well being. Since an ergonomics standard dealing with the evaluation of work system design is not yet available this might be rather complicated. However, at least comparative studies, comparing different design solutions incorporating more or less ergonomics principles, might help to determine, whether ergonomics really matters in design; at least the above mentioned results from hazard analyses seem to confirm the hypothesis that human factors are a crucial factor for safety in the design of work systems. Another way to test for the importance of human factors could be the experimental analysis of different design alternatives on simulators, which would allow for a better control of confounding conditions. First results from our laboratory (Meyer, 2006; Nachreiner et al., 2006; Nickel & Nachreiner, 2006) would seem to indicate that an ergonomic design, taking human factors into account, does in fact have effects on operator activities, performance, work load and system efficiency; although the available results would also seem to indicate that there are important interactions between design characteristics, operational states, and specific operator tasks / activities within process control, which would make simple generalizations impossible and suitable recommendations rather complicated (Meyer, 2006).

Such results would argue for more general but at the same time also for more specific (or context related) provisions in ergonomics standards: more general with regard to specifying general principles to be worked out and tailored to the contexts and tasks at hand, and more specific in specifying conditions when to apply which recommendation / specification in which form (e.g. specifying requirements for the presentation of information depending on the operational state of the system, i.e. normal or abnormal operations) – where this is possible and required. It will be interesting to see how ISO/CD 11064-5, which is still under development, will deal with these problems.

This raises the question of how compliance with ergonomics standards can be tested. If there are clear specifications of physical characteristics, e.g. font size on screens at given viewing distances, this should be no problem (in reality, however, this is a common violation), and the same is true for most provisions concerning the physical environment. So 'specification standards' are rather unproblematic. The opposite, however, is true for so called 'guideline standards', where principles or guidelines have been (and can only be) specified, since it is impossible to specify the provisions for any kind of situational context, and this even applies to more context specific standards, like the software design standards of the 9241 series for office tasks. Although in these standards some efforts have been made to specify how compliance should be tested a closer examination clearly shows that compliance (especially full compliance) with general principles, unless specific criteria have been exactly specified, cannot be tested and demonstrated. On the other hand non-compliance can usually easily be demonstrated, since any observed violation is a demonstration of non-compliance. Compliance with such standards must thus be assumed as long as a provision cannot be falsified – after adequate testing of course – which would also have to be specified in the standard itself.

This definitely is a problem for any summative evaluation, where the aim is to show compliance with the provisions of a standard for a pass/fail decision and where any violation would lead to a fail - independent of how severe that violation is. This is one of the problems of testing software against the provisions of standards. The question here is whether any violation leads to a fail, or whether it needs a severe violation, leading to the question of whether the severity of a violation can be quantified with such guidelines. The next problem would then be whether such (mild?) violations can be compensated by other characteristics going beyond their (minimal) requirement(s) - which again is a problem with guideline standards (when is such a provision over accomplished?). The standards themselves do not provide any information on these points. On the other hand this is not a problem for any formative evaluation where the aim is to improve the design solution, i.e. make it better than any possible design alternative. Evaluating design solutions against a standard (and the principles and guidelines specified in it) quickly makes clear where design improvements can (still) be achieved; but the question remains whether it needs to be improved to comply with (legal) regulations or negotiated contracts.

It should be kept in mind that most ergonomics standards have been developed with a view to this design orientation, and not to a certification orientation, which, however, seems to be increasing over the last years. Considering this trend within the context of legal requirements or (to be) negotiated contracts (between manufacturers and clients or managers and workers' representatives) it would seem necessary to develop a standard giving guidance on both, formative and summative evaluation of the ergonomics of work systems – in order to make the available ergonomics standards more useful and functional in improving the design quality of work systems.

At the same time it would seem necessary to restructure and adapt the body of standards for such purposes. This process has now been started with a new, second revision of ISO 6385. After reviewing the available International and European standards it became obvious that relevant provisions were scattered among different standards, which made them difficult to access, as well as multiple specifications in different standards. It has thus been decided to try to revise the ergonomics standards and to specify the basic principles within a general standard - with references to more specific standards for more detailed specifications. Since ISO 6385 is the basic ergonomics standard, this standard is now under discussion for a thorough revision. The basic idea is to transform this standard into a multi-part series of standards, where the basic principles would be described. It is thus intended to have a (still unknown) number of standards to deal with these basic principles a little bit more in detail and to give advice where to find more relevant specifications. As of to today the structure looks like a first part with the 'credo' of ergonomics (what it is about), the basic terms and definitions, which would be binding for all other standards, and the basic concepts, e.g. the man-machine model, or the stress-strain concept, specifying operator work load and operator responses to this work load as central and integral elements for the design and evaluation of work systems. This would make clear that it is not only the performance (e.g. in time or errors) of the operator but also her/his internal responses (e.g. work strain, fatigue, and/or monotony) that are crucial in the evaluation of a work system.

Part 2 is intended to deal with the principles and methods of work system design, specifying the relevant design tasks from system specification over function analysis, function allocation to task design, which could become the topic of a Part 3, since designers are usually less familiar with the importance and principles of task design and criteria of well-designed operator tasks. Parts 2 and 3 would thus deal with the design of the human machine task interface, which according to the priority of well-designed work tasks must precede the design of the interaction interface. So this sequence would also be adopted in the series of standards.

Part 4 would deal with principles of equipment design, specifying among others principles for the design of displays and control actuators (or the human machine interaction interface), for (previously) well-designed operator work tasks.

Part 5 would deal with principles of workstation design, and Part 6 with the design of the work environment.

All these standards (or parts of the basic standard) could and should reference the more detailed or more specific standards relevant in their context matter. This should enable the user of the standard to get a clearer picture of the interrelatedness of the different design tasks from an ergonomics point of view and where ergonomics standards or ergonomists could play an important role in improving the design quality of a work system.

Part 7, finally, would be the part where principles for the evaluation of the design quality, both for formative and for summative evaluations, would have to be laid down, again pointing to other standards giving guidance or specifications for such evaluations.

This should result in a more accessible body of standards, more accessible especially for non-ergonomists, e.g. designers and customers, who might get a better understanding of what this field is about and where and how it can be profitably applied. This then could lead to a more extensive consideration of ergonomics in the design of work systems and to a more extensive application of ergonomics knowledge as laid down in ergonomics standards, be it voluntary or mandatory by legal regulations.

PROSPECTS

The application of ergonomics standards, especially in the design of complex systems, can however only be a first step for implementing ergonomics into the design of work systems, both into the design process as well as into the results of this process, since ergonomics standards will never be able to specify complete (and specific) solutions for such systems, and especially not for complex systems. This can easily be demonstrated by the - unavoidable - guideline character of a lot of these standards. Specific design problems - and complex work systems like process control systems are very specific design problems - will need specific solutions, which cannot be specified in advance in standards, and thus require a deeper understanding of ergonomics.

What can be specified are the general principles and some rather simple rules. However, in order to be able to transform these principles into specific design solutions some background in ergonomics, including the regulation and control of work(er) activities, their bases, limitations and effects, as well as in the analysis and design of work activities, would seem to be required - or at least advantageous. Otherwise the transformation of the general principles into the specific design problem might result in a dysfunctional solution. These problems might lead to the awareness that in order to comply with legal or negotiated requirements (or to increase the possible benefits), e.g. in applying the existing ergonomics standards in order to improve operational safety, it might be better or even necessary to directly involve genuine, professional ergonomics competences to meet ergonomics requirements, making the best use of the available ergonomics evidence. The functional role of ergonomics standards within the design process and in the evaluation of design solutions might therefore have to be (re)considered.

Whereas ergonomics standards used to be considered as specifications of legal or negotiated (minimal) requirements with regard to human factors this might only be one half of the truth. The other half might thus be to better integrate human factors into the design by motivating or necessitating designers or customers to become interested in human factors and get themselves more involved – or to engage professionals with an adequate background to take care of ergonomics requirements if they feel that their own experience with human factors and the state of the art laid down in ergonomics standards might be inadequate for solving the problems at hand.

Applying ergonomics or human factors standards in the design of complex work systems can therefore only be a first, although quite successful and promising step in improving operational safety by integrating human factors into the design process - and its results. A necessary subsequent step would be to go on from there and to really incorporate the whole body of human factors knowledge into the design, beyond the (minimal requirements) specifications laid down in the available human factors standards - although the application of such minimal requirements should already have a considerable effect on effectiveness, efficiency, safety and reliability of the system and the operators' work load, health and safety. Adopting a human factors perspective - with a view to human-centred system design - and taking professionally account of human factors in the design process, however, should make an essential step forward in achieving these design objectives. As mentioned already in the introduction: as long as there are still human operators in such systems, and the prognosis is that they will remain there (– for a lot of different reasons –), the design of such work systems has to be based on human factors and appropriately designed human work activities; otherwise only suboptimal - or even dangerous - solutions will result.

Nevertheless another question still to be addressed is how the application of at least basic ergonomics knowledge, as laid down in the standards, can be made mandatory or voluntarily increased for a wider field of installations than today, since the voluntary application of these standards or even the whole body of ergonomics knowledge still seems to be the exception rather than the rule. Besides or in conjunction with more directly referencing human factors or ergonomics and its standards in the relevant legislation or agreements, for which it would seem necessary to inform legislators and parties to negotiate about the existence of such standards, human factors standards might help to make these parties involved in negotiating about work system design and operation more aware of some up to now definitely less than appropriate observed evidence for achieving or improving operational safety, i.e. integrating human factors into the design and operation of work systems, from the design of adequate operator work tasks to the design of adequate operator-machine interaction interfaces.

Revised: 07/06/2006
Accepted: 14/09/2006

BIBLIOGRAPHY

[1] Health and Safety Executive (ed) – The explosions and fires at the Texaco Refinery, Milford Haven, 24 July 1994. A report of the investigation by the Health and Safety Executive into the explosion and fires on the Pembroke Cracking Company Plant at the Texaco Refinery, Milford Haven on 24 July 1994. London: HSE Books, 1997.

[2] ISO 6385: 2004 - Ergonomic principles in the design of work systems, Geneva, ISO, 2004.

[3] ISO/WD 6385: 2005 - Ergonomics - Ergonomic principles in the design of work systems. - Part 1: Basic concepts, terms and definitions, Geneva, ISO, 2005.

[4] ISO/WD 6385: 2005 - Ergonomics – Ergonomic principles in the design of work systems. - Part 2: Principles of the ergonomic design process. Geneva, ISO, 2004.

[5] ISO 9241-10: 1996 - Ergonomic requirements for office work with visual display terminals (VDTs) - Part 10: Dialogue principles, Geneva, ISO, 1996.

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

[7] ISO 10075: 1991 - Ergonomic principles related to mental workload. General terms and definitions. Geneva, ISO, 1991.

[8] ISO 9241-10: 1996 - Ergonomic requirements for office work with visual display terminals (VDTs) - Part 10: Dialogue principles, Geneva, ISO, 1996.

[9] ISO 10075-2: 1996 - Ergonomic principles related to mental workload - Part 2: Design principles. Geneva, ISO, 1996.

[10] ISO/CD 11064-5: 2005 - Ergonomic design of control centres - Part 5: Displays and controls. Geneva, ISO, 2005.

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

[12] KAPPELMAIER, R. - "Human Factors – Nutzen und Grenzen", In: VDI-Gesellschaft Verfahrenstechnik und Chemieingenieurwesen (Ed.). Anlagen-, Arbeits- und Umweltsicherheit, Düsseldorf, VDI-GVC, 2002, pp. Ü 03:1-6.

[13] MEYER, I. - Effektivität der Prozessführung und psychische Beanspruchung der Operateure bei unterschiedlich gestalteten Oberflächen eines Prozessleitsystems. Doctoral dissertation, Universität Oldenburg, 2006 (in press)

[14] NACHREINER, F., NICKEL, P., MEYER, I. - "Human factors in process control systems: the design of human-machine interfaces", Safety Science, 2005, 44, 5-26.

[15] NICKEL, P., NACHREINER, F., MEYER, I - Möglichkeiten und Grenzen der Übertragbarkeit von (software-) ergonomischen Grundsätzen der Dialoggestaltung von Büro- auf Prozessleitsysteme. In Gesellschaft für Arbeitswissenschaft e.V. (GfA) (Ed.), Arbeit + Gesundheit in effizienten Arbeitssystemen. Dortmund: GfA Press, 2004, pp 463-466

[16] NICKEL, P., NACHREINER, F. - Presentation of information for process control operations - evaluation of design quality by mental workload assessment. In: ISSA Research Section (ed.), Design process and human factors integration: optimising company performance. Proceedings of the International Symposium, Nice, France, 1-3 mars 2006. Paris: INRS, 2006 (CD-Rom)

[17] PAPIN, B. - Human factors and nuclear systems design: a project-long concern. In: ISSA Research Section (ed.), Design process and human factors integration: optimising company performance. Proceedings of the International Symposium, Nice, France, 1-3 mars 2006. Paris: INRS, 2006 (CD-Rom)

[18] ULICH, E. - Arbeitspsychologie. Zürich: VdF, 2006