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Human Factors Engineering at Design Stage: Is There a Need for More Structured Guidelines and Standards?

Farzad Naghdali*, M. Chiara Leva, Nora Balfe, Samuel Cromie

Centre for Innovative Human Systems, Trinity College Dublin, Dublin 2, Ireland
naghdalf@tcd.ie

Human Factors Engineering (HFE) focuses on the application of human factors knowledge to the design and construction of socio-technical systems. The objective is to ensure systems are designed so as to optimise the human contribution to production and minimise potential for design-induced risks to health, personal or process safety or environmental performance (OGP, 2011).
The ISO standard ISO 9241-210 (2010), Ergonomics of human-system interaction, requires that all new facilities projects apply the principles of Human Factors Engineering (HFE) during early design stages. In practice this means ensuring, as a minimum, that every new facilities project is screened in collaboration with the end users to identify whether there are any “hotspots” (risks, issues or opportunities) associated with the scope of the design project that justify further HFE activities. Further standards detail these activities, including physical and cognitive ergonomic assessments of the operator tasks, the equipment they will use to complete those tasks, and the environment in which they will be undertaken. However, the standards need to be generic enough so as to avoid being tailored to any specific design process; this in turns generates a need for more specific guidance on different processes and activities supporting a more holistic approach to guide Designers, Operators, Risk Assessors and Project Planners at design stage. This guidance should help stakeholders identify and recognise the value of Human Factors Engineering considerations to optimise and guide some of the solutions devised in the early stages. Such an approach should help avoid more costly intervention later on in the lifecycle of the product or plant being designed and the possibility of undesired events related to miss-conceived Human Machine Interactions. There is often a need to demonstrate that this small initial investment in engineering to consider Human Factors aspects can result in a major reduction in the operational life-cycle costs and improvement in the conditions at work. However, this is often only demonstrated retrospectively after minor or major accidents. Strong operational performance can only start with good design and an understanding of what constitutes good design requires a detailed knowledge of how humans interact within the work system. The problem is whether the currently available standards and guidelines of the process industry provide sufficient guidance for a framework to be practically used by process engineers, discipline engineers, human factors engineers, ergonomists, project management and operational/maintenance line management during decisions to be made in preparation and execution of projects?
This paper will start by observing and analysing the problem and presenting examples. The study will be continued by discussing what is currently available and performing a small gap analysis against concrete needs of case studies taken from the industry. Addressing those gaps will be within the scope of future research.

1. Human Factors Engineering impact in Design: relevance of the problem

The demand of industry for safe and efficient operations has increasingly shifted the role of the human in the system from primary actor to supervisor of an automated process. This is particularly true for rapid transport systems, manufacturing production lines and computerized systems; however a certain degree of attention towards human-machine interaction is always required even if it is just for maintenance, commissioning and sporadic supervision (Leva et al., 2012). Additionally, when the complexity of the

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system increases, the reluctance of the designers to substitute the operator with automated functions will increase as well. This is because the ability of the human to control the system in unforeseen circumstances can help the system to keep functioning normally (Hale et al., 2007). Computers do not have this ability and therefore cannot be considered as the only available source of control. Therefore it is preferable to have the human as a final authority working with the computerized system. Hence, recently in most of the industries the human operator's task to operate and control the system is considered crucial (Nazir et al., 2013).

On the other hand there are accidents in which the human operator is overloaded with information and alarms that will affect their performance (ATSB, 2013). In accident investigations, design inadequacies are often mentioned as a major contributing factor (Hale et al., 2007) and human error is almost always described as a major cause of accidents (OGP, 2010). Considering the change of the human role to a supervisory role, the human-machine interface (HMI) is becoming an increasing risk for industries, one which better design can play a significant role in managing. Therefore, it is required to have the human machine interface carefully designed to meet the operator requirements and provide information and procedural guidance for the operator to improve the functionality of the system (Øwre, 2001). In fact the design of machinery and equipment and safety can no longer be considered as two separate tasks (Bernard and Hasan, 2002) and human factors engineering and ergonomic studies can help companies identify practical solutions for issues regarding the HMI (EU-OSHA, 2006).

An example of inadequate human-machine interface design comes from the Three Mile Island incident which revealed the impact of HMI and procedure design on human reliability (Kim, 2001). Key indications were not visible to the operators leading them to follow a procedure which escalated the situation. This accident raised the question about the efficacy of the human factors supports in standards for designers and maturity of the practices (Boy and Schmitt, 2013). International standards are available to guide the application of HFE in the design phase (discussed in the following section) but these are by necessity general and might not be sufficient to support the HFE assessments of the design. This is illustrated by the fact that high reliability organizations in safety critical areas, such as the aviation or nuclear industries, have often developed their own internal standards to provide more specific guidance on HFE assessment and safety by design issues. There are several attempts in the field of design for improved approaches such as Human-Centred Design (Maguire, 2001), intelligent human-machine interface design (Tendjaoui et al., 1991), user needs analysis (Lindgaard et al., 2006), Safety by Design (Kletz, 1996) and Human Factors Integration (Widdowson and Carr, 2002). The intention of these approaches and methodologies is to prevent accidents and eliminate the source of the hazard as well as improving efficiency and well-being.

There is also the possibility to provide more support in the design phase regarding human factors by learning from accidents and incidents. Different industries can learn from each other and historical data can contribute to increasing safety but the learning mechanism needs to have a good understanding of the culture, constraints, objectives and the design procedure of the target industry (Drogoul et al., 2007). Although learning from accidents and analysing them is very important for improving knowledge, on the other hand the learning procedure and the loop to give feedback to the engineering strategy is slower than technology developments, thus the learned lessons may lose their value and become inefficient (Rasmussen, 1997). In addition, new technologies are already introducing new challenges for the safety by design techniques in that there may not be any historical data available for them. Similarly market and financial issues are putting more pressure on the designers, thus the opportunity for thorough safety through design studies is decreasing (Leveson, 2011). In the past the development of a new technology was much slower than that in the present and it could allow enough time for the hazards to emerge (Leveson, 2011).

2. Existing standards and industrial practices for HFE in Design

To support the challenging task of the design team there are number of standards able to provide some guidance on the minimum requirements in terms of human centred design: for example, ISO 6385 – Ergonomic Principles in the Design of Work Systems (2004) outlines how technological, economic, organisational, and human factors can affect the work behaviour and well-being of people within a work system. The general principle underlying the standard is that interactions between people and the components of the work system (e.g. tasks, equipment, workspace and environment) should be considered during the design stages. Each design stage is described and appropriate ergonomic principles and methods for each stage are listed. ISO 11064 - Ergonomic Design of Control Centres (2006) provides nine principles for the ergonomic design of control centres and guidance on specific aspects of control room design, including layout, workstation design, controls and displays, and environmental requirements. ISO 12100 – Safety of Machinery (2010) suggests a five step methodology to perform risk assessment at design stage and the overall strategy requires designers to take into account the safety of machinery for their whole life cycle, considering usability, maintainability and cost efficiency. EEMUA 191 (1999) is an industrial standard developed by the Engineering Equipment and Materials Users' Association to support the design of alarm systems taking into account the requirements of the human operator receiving and responding to those alarms, while EEMUA 201 (2010) is focussed on the design of HMIs and gives guidance on areas such as display hierarchies, the design of the screen format, and the attributes of the environment which may affect the use of the HMI. These standards define the minimum requirements and it is the decision of the designers on how to optimize and utilize the systems to increase the satisfactory level of the users. This systematic approach is fairly generic and does not provide technical support for the designers. While it recommends foreseeing the design uses nonetheless there is no discussion regarding the methodology to conduct this verification. Increasingly rapid prototyping and participatory approaches are proposed as methods to evaluate the design. These approaches have been commonly used for products that will be produced in large numbers (Sinclair, 2005), although it has traditionally been more costly and time consuming to apply this approach to the design of a control room, limiting the ability to apply these methods in this context. However a possible substitution for prototyping can be provided by the use of 3D models of the buildings, structures, or control room. Reviews of these models can be undertaken with the involvement of the operators. The 3D model is a more natural representation that does not require decoding of 2D technical drawings and thus facilitates the operator in identifying potential issues regarding the proposed design. This approach can be considered as an example of human centred participatory design, able to support a better understanding of the user's needs and a more solid starting point for the designers to deliver a safer design. Such participatory reviews of designs do not negate the need for guidance for designers at an earlier stage as they should be facilitated as early as possible in optimising their design for human operation. The above-mentioned standards can be used in combination with 3D participatory review, however the process has not been detailed or suggested clearly in any of the before mentioned standards. So while on the one hand the ISO 9241-210 (2010), Ergonomics of Human-System Interaction, requires participatory human centred approaches it does not provide technical details on what specific aspects should be considered and how to concretely carry out such a process, the link with the more specific standards such as ISO11064 for the Ergonomic Design of Control Centres and or the ISO 12100 (2010) on Safety of Machinery is not structured or suggested in any clear way and as a result companies must introduce internal standards to tackle the problem.

Table 1: Summary of the HFE issues in various areas of System Design

HFE Area of Design	Related existing standards / best practices	Possible issues/ gaps
Design of physical built environments	ISO 6385 (2004) Ergonomic principles in the design of work systems	The standards do not provide any practical guidance on how to actually review the built environment at the design stage involving users (such as 3D reviews)
Design of machinery / electrical systems	ISO 12100 (2010) Safety of machinery / EEMUA 178 (1994) A design guide for the Electrical Safety of Instrument Control Panels	The standards are seldom applied in the industry and they do not specify to what machinery they should apply
Design of control rooms, HMI for information systems	EEMUA 201 (2010) / ISO 9241-210 / ISO 11064 (2006) Ergonomic design of control centres	How to review the mimics of control centres is not specified and the use of task analysis is not clearly suggested
Design of information systems and alarms	EEMUA 191 (1999) / ISO 11064 (2006)	As above
Workload assessment for design	ISO 11075-3 (2004) Ergonomic principles related to mental workload	Not really applied in the industry
Design of manuals and procedures	ISO 12100 (2010) / ISO 18152 (2010) Ergonomics of human-system interaction – Specification for the process assessment of human-system issues	The standards specify how to assess processes but not how to translate them in to good instructions and procedures
Risk assessment at design stage	ISO 31010 (2009) Risk management – Risk assessment techniques	Little guidance on what standards are available for human reliability analysis

3. Examples of issues in a concrete case study

In order to emphasise the importance of HFE in this chapter a few concrete examples of the application of Human Factors during the design of a gas plant will be presented. The selected case studies come from oil and gas design projects and have been selected because the human role has a significant importance in the process industry. The operators and the maintenance crew are the two main groups of users that interact with the system. As mentioned in the previous section, the insufficient detail in the publically available standards has led some companies, including those involved in the case studies, to develop internal standards to pursue safety during design. The aim of industry standards is to provide guidelines and support for designers and define general rules and decision criteria during the design review. In this case, the system was reviewed in a set of workshops and each HFE workshop aimed to detect the relevant issues regarding the human and system interaction. This paper will present the reviews relating to cognitive ergonomics of human-machine interaction (HMI), the 3D model, and alarm management.

The first example is the evaluation of the human machine interface for a new control room within an oil and gas facility. The control room was designed to enable the operators to control the processes and functions of the facility and perform the necessary actions when required. The review of the control room was undertaken in accordance with ISO 11064 (2006) International Standard as well as the company internal standards. The review was made in a workshop with a team of experts using a checklist that considers the control panel in order to evaluate the design in terms of the operator's ability to control the system through the designed control panel effectively and efficiently. During the cognitive review the HMI was reviewed to check that it was clear and understandable for the operators. This covered aspects such as overall system authority, information requirements, conformity with operator mental models, information coding, system feedback, and dialogue structure. However the review cannot be completed without running a test through some of the main tasks the operator has to perform on them. The need to supplement the guidelines from international standards reveals that although the ISO 11064 (2006) is a good starting point to set the design strategy it may not be adequate in terms of supporting the entire evaluation in the review sessions. The available standards do not have any recommendation for structure of the system to suggest recommendations, thus the company designed a recording system themselves. This system not only records the recommendations, suggestions, or action items but also describes the comprehensiveness of the feedback of review team and justifies the causes of the change. The recording and reporting mechanism for communicating with designers regarding the recommendations also relies on making points on a printed picture of the display as the recording system cannot provide all the necessary information for the designers in case of the display screen.

The next case was alarm management within the process plant control system. In order to support the design of the alarm system, a private industry standard has been developed. This standard regarding alarm management is derived from EEMUA 191 (1999) and the structure of the review team is based on contribution of designers, HFE experts and operators. The alarm criteria are defined in the internal standard and for each specific alarm the designers have defined the specific parameters. In general, the priority of the alarm is based upon whether the operator has to act, and how much time they have to act before escalation of the event. The review team analysed each alarm that can be generated to make sure that the alarm is necessary (i.e. that the operator must act upon it) and that the operator has enough time to perform any necessary actions before the event is escalated, e.g. the designed instrumented protective function (IPF) or instrumented protective system (IPS) began to start. To make such analysis, the internal standard of the company provided a flowchart to structure the analysis and also investigate the necessity of the alarm. During the workshop, it was clear that the system designers and engineers had not considered the HFE principles of alarm management when designing the system, and in fact it is necessary to begin such workshops with a short presentation of the principles in order to ensure that all participants are aware and understand them. At times, the engineering standards they relied upon appeared to explicitly contradict the principles of alarm management creating situations which required complex solutions. The clarity of the HFE principles is critical in these situations to ensure that such situations can be satisfactorily resolved. However the alarms are always considered individually while in reality some scenarios may generate multiple alarms.

The last example refers to the design review of built environment derived from the P&IDs. The company practices a participatory design approach because it was considered the best practice to accomplish a better design. Also the company adopted the use of 3D model to review the design as the use of P&IDs alone may result in missing some issues (e.g. low point, accessibility, maintenance issues etc.). A 3D graphical representation of the system can be employed to conduct the HFE review session. In the case study chosen the review took place in a brainstorming session among the designers, human factors experts and operators. This enabled the review team to find issues that may be discovered only when considered in combination with actual tasks (e.g. the accessibility and visibility of key components, the safe positioning of equipment and vents, and the clear labelling of equipment). Those findings had a clear impact on improving the overall safety of the plant but could not have been easily identified without the use of a 3D model. Although in ISO 9241-210 (2010) it is mentioned that the users are to be involved nevertheless the end user's involvement in the design procedure or any other alternative approach to take into account the user's requirements was not delivered to support the designers.

4. Possible areas of improvement in HFE at the design stage

Today's sociotechnical structure is very complex and interrelated and requires a new approach to safety. Companies are facing difficulties in achieving a balance between safety, time and budget and a new oversight regulation or standard methodology could help them to ensure the safety more effectively (Leveson, 2011). Additionally, designing a complex system is a difficult task and designers need support. The standards discussed in this paper provide the basis for that support by giving guidelines and suggested approaches, but standards are necessarily broad in order to deliver their support to the widest possible range of end users. The need for more detailed guidance to support the design process is evidenced by the additional material used internally by companies to tailor the international standards to their operation. Although much of the available guidance is available to engineers and design teams (often it is specifically targeted at these groups), the ongoing need for detailed review sessions reveals that these groups are not fully assimilating HFE information.

Integration of HFE principles within broader engineering and design standards may be one way to achieve this. Too often, only human factors specialists are aware of the existence of HFE standards and the principles contained within them. This means that the design reviews may be the first point when human factors principles are considered in the design, when in reality it should be a check point to ensure that they have been applied correctly. It is also important to ensure that the HFE standards are aligned with the relevant engineering standards, to ensure that designers are not receiving conflicting guidance from the two sets of standards. In order to best achieve this, engineers and designers should be provided with basic training in HFE to ensure that they understand the basic principles and are capable of correctly interpreting the information contained within the standards and applying it to their designs. In addition to the use of standards, designers can benefit from a clearer understanding of how their designs have performed in operations. As discussed, importance was placed on capturing the decisions made during the review meetings in sufficient detail to provide meaningful feedback for the design team. However, although the design review can decrease the number of hazardous situations or mitigate their effects, it cannot detect all the risks associated with a new design and these risks may be replicated in the future design projects conducted by the team despite being known in the operations field. Most design teams conclude their work following the implementation of the design or at best after the closure of the snagging list during the initial operations. They therefore do not have the opportunity to learn lessons from the operation of their design, and understand how their design is influencing operations. A new HFE method that can close this design loop and provide operations feedback to future design teams could provide very valuable design input, increasing overall safety and efficiency. In this paper the authors have tried to point out the gaps to be addressed by HFE at design. In future the objective of the study is to collect more data regarding the available methods and practices in industries to study them, justify the added value of implication of the methodology by industries and covering their weaknesses to support designers and increase the reliability of the systems.

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