This paper will focus on a user-centred approach to control centre design for the nuclear and other industry applications. Human factors issues exist in nearly all aspects of control centre design. To effectively integrate human factors into such a process a comprehensive and systematic approach must be taken. Control centre design and modernisation projects consist of several phases, e.g., analytical work; conceptual design; prototyping and mock-ups; verification and validation of design; etc., and various human factors issues exist in all phases and cover a wide variety of concerns. Examples are function analysis and allocation, staffing and organisational issues; etc. The Institute for Energy Technology (IFE), which also operates the OECD Halden Reactor Project, has been using the user-centred approach to control centre design, which addresses issues such as those listed above. The main feature of this approach is the development of a so-called control room philosophy (or rather control centre philosophy), often combined with the application of virtual reality technology in the design process. While we argue that human factors input should be incorporated in all project phases, our practical experience varies, often constraints such as money, time, etc., restrict human factors involvement. In general, human factors issues are still addressed in a piecemeal fashion, with the most pressing concern at the moment being considered. We will summarise lessons learned from various industries in terms of how human factors input is being considered, applied, and where deficiencies remain.

1. INTRODUCTION

There is increasing recognition of the need to apply human factors principles to a design at as early a stage in the design process as possible. A philosophy for the control room, or rather control centre, provides the foundation for achieving this and developing a control centre concept based on functional and operational requirements. It identifies the roles of operators in addition to all the functional requirements of the control centre, its support facilities, and its infrastructure. The philosophy is viewed as a functional requirement specification, which later guides the design, development and selection of control room layout, systems and technologies. An important aspect of this approach is the early involvement of end-users in the design process. This control centre philosophy, combined with the use of virtual reality technology, is the main feature in IFE’s user-centred approach to control centre design and upgrading projects. Virtual reality is an interactive medium that assists in achieving this objective because it enables designers to examine evolving designs from the viewpoint of the end-user, reducing the risk of costly design-induced operational problems while at the same time improving the quality of the final design.

2. CONTROL CENTRE PHILOSOPHY

The basis and novelty with this approach of developing a control centre philosophy is the concept of a total perspective for the entire control centre. By total perspective it is meant that all aspects of a control centre’s functions are systematically examined, including operational, administrative, and social aspects. The concept includes not only issues on human-machine interfaces, I&C or operational topics, but also administrative work and the infrastructure necessary to run a process across all states and continuously year round. It is therefore necessary to consider the entire activity that will take place within this environment. Important bases for this work have been ISO Standard 11064 and IEC Standard 964, [1, 2]. The main topics typically included in the philosophy are the following:

- The role of the operating crew and the individual operators, based on the operational requirements set by the process.
The organisation and staffing of the operating crew based on the earlier identified roles.

Overall functions for the control centre based on the identified roles.

Working environment issues.

Infrastructure supporting the control room.

Functional layout of the control room.

Workstations for the different operator positions.

Human-system interfaces, (meaning all user interfaces), including all information presentation, human-system interaction including manual process control, and available operator support systems.

In addition to what has been listed above can also issues such as operating procedures and operator training be included.

### 3. THE DESIGN PROCESS

When considering a control centre philosophy it is important to take an overall view and see the context in which the philosophy is developed. Control centre design and modernisation projects consist of several phases. At IFE/Halden we have advocated a very iterative design process where the different components in this process are well integrated. The design process requires a multi-disciplinary approach including expertise from primarily areas such as operation (operators), engineering - including instrumentation and control systems, computer technology, and human factors.

A design process can be described in several ways dependent on the level of detail and aim of the description. Figure 1 shows one way of describing an overall design process and indicates the important characteristics that IFE/Halden stresses.

Initially, the design work starts from a basic concept or idea, a design concept. This design concept should typically be based on the requirements identified in the control centre philosophy, (step 1 in Figure 1). Usually, this early step in the design work requires analysis of the existing situation even if the analysis typically does not have to be very extensive in terms of comprehensive function and task analyses.

![Figure 1. The overall design process](image)
Comprehensive function requirement analyses, function allocation between human and the technical system, and task analyses are the three basic elements in the next step of the design process, (step 2). At this point operational experience also becomes an extremely important input. The result of this step provides the basis to start up the preliminary design. The task analyses identify the information requirements and manual process control functions that have to be present in the control room.

The next phase, preliminary design (step 3), usually follows a top-down approach and after some time leads into the detailed design phase. Typically, the design work is split into different parts where certain areas or components of the control centre can be designed in parallel.

During this design specification period prototyping is an essential part of the work. It is in this context that virtual reality technology has shown to be a very effective tool by improving communication within the design team, increasing the insight of the design among the involved parties during the work process and reducing the time for all parties to have an insight into the design. Our experience shows that virtual reality technology can play an important role in the entire control centre design process. What is built is a “virtual mock-up” which can remove the need for a physical mock-up.

In addition, it is also necessary to use graphical software tools, user interface management systems, to be able to prototype VDU based user interfaces for the control room.

As soon as prototyping has started the next phase should begin in parallel to evaluate the outcome in terms of human factors verification and validation (V&V), (step 4). This can be performed on different levels and with different degrees of ambition depending on the type of control centre/room being developed and the environment in which it will operate. The idea is to develop simple prototypes using rapid prototyping techniques and to test these early in the design process. The aim is to test solutions and ideas as early as possible, and gain feed back which then can then be used in the continued design work. The V&V activities become important tools and support for the design team during the design process, and not a final sum up in the end of the design work. Such an approach means that the cost and usage of time for design changes can be kept at a minimum, and at the same time have the best possible solution identified, [3, 4, 5].

The described process implies that different V&V methods and techniques are used at different stages in the design process. For example, at an early stage the focus is on verification using simple techniques, even paper based. Later in the process validation work starts, firstly by applying simple simulations, later more advanced. In terms of focus for the V&V process, the first tests are verifications of concepts, after that come tests of the performance of individual control room systems or parts of systems, and finally integrated system testing of several systems and the entire control centre.

This prototyping and design work have to be documented in design specification documents which then will guide the design and later the entire implementation work. Again the virtual reality environment has been found to be a good medium for keeping track of the design documents developed, revisions done during the design phase, and the rationale behind the revisions.

The result from the V&V work is fed back to the preliminary and detailed design to support and improve the further development. In other words, the evaluation activity is a method to strengthen the design process throughout the entire activity. After the design specifications are documented and finished in terms of frozen detailed design specifications, the implementation work can begin (step 5).

A final verification and validation activity is usually performed at the end to confirm the entire design (step 6).

4. OUR EXPERIENCE

The Institute’s experience in control centre design and modernisation provide informative ‘lessons learned’ in terms of the application of human factors expertise, an understanding of the issues and practical constraints, as well as the problems which can result from not addressing these issues. These lessons and experiences, having been drawn from projects in a variety of process control industries, e.g., nuclear, petroleum, power distribution, steel, chemical, offer insights from set of diverse perspectives on how human factors is currently applied in control centre design.

In general it has been our experience that human factors issues are still addressed in a fragmented fashion, with the most pressing concern at the moment being considered. While industries are
increasingly recognising the need to apply human factors expertise as early in the design process as possible, very often human factors is still not built into a project in a comprehensive way. Industry is therefore failing to gain many of the benefits and cost savings of using human factors throughout a project. For example, the often encountered ‘piecemeal approach’ to upgrading typically leads to a lack of integration of the systems in the control centre with different interfaces, interaction methods, and disparate information across the control room. Unfortunately for the human factors community there still remains an urgent need for evidence to justify the inclusion of human factors in an integrated and comprehensive manner. In many cases human factors is still perceived as a luxury ‘add on’ rather than a necessary requirement when upgrading control centres. Expressions such as, “Operators have been able to deal with problems in the past so they should be OK in the new control room” are still heard – ignoring the fact that modifications and upgrades often involve changed or new functions in the control centre, increased complexity and fewer operators.

Clear differences do exist however between safety critical and non-safety critical industries. The following sections outline some of the lessons and experience drawn from IFE’s work across this spectrum.

4.1 Absence of Efficient Human Factors Methods

The absence of methods available to qualitatively and quantitatively prove and demonstrate performance improvements through control centre modifications has made it easier for decision-makers to neglect the human performance aspects of the design. Often the very fact that substantial amounts of money have been spent in a control centre and that ‘the latest technology’ has been introduced, has been taken as justification enough that improvements will result. However, in high risk industries, especially those with strong regulatory requirements, this argument is no longer sufficient. Licensing and inspection bodies are beginning to require stronger evidence of comparable or improved performance following control centre upgrades. Stronger arguments and evidence quantities improvements are however being gathered, for example, a recent upgrade to a Dutch NPP (Borssele) resulted in an order of magnitude reduction to core-melt frequency, [6].

As a further example, IFE/Halden is also contributing research and techniques to provide such evidence. This work involves developing and applying robust, valid, quantitative methods and measures, which allow direct ‘before’ and ‘after’ comparison between two versions of a control centre. Such evidence allows designers and utilities to evaluate new designs and to answer concrete questions based on sound experimental findings, such as ‘is the new control centre better than the old control centre, and if so, by how much?’ The provision of such evidence might be important not only for regulatory acceptance or for demonstrating the ‘success’ of the project, but also as one contributor for providing objective evidence of the importance of considering human performance.

4.2 Commercial Environment and Late Introduction of Human Factors Engineering

In the current commercially orientated markets, particularly in the deregulated electricity market, there is increasing pressure on all aspects of control centre modification work, e.g., reduced build times. This pressure can be so great as to even halt such work, as in the current situation in the Swedish nuclear modernisation programme. In such an environment human factors can be seen as expensive and time consuming – often only identifying problems and bringing bad news –especially if introduced towards the end of a project.

4.3 Cost, Time Constraints and Limited Appreciation of Human Factors

The great advantage with an iterative design, as described earlier, is the ability to identify potential problems and solve them before they become a permanent part of the design. Despite the obvious benefit of hindsight it has been possible to identify many control centre problems that could have been solved cheaply early on in the design process with the appropriate human factors knowledge. Unfortunately late identification of problems reduces the chances of them being removed, often leaving operators with a daily source of annoyance or potential safety/efficiency problem. The reasons for not adopting an iterative approach are complex, but it has been our experience that cost, time constraints, and limited appreciation of the human factors discipline play an important role in determining whether human factors are included within a project at all. Mentioning limited appreciation of the human factors discipline, it is
not unusual to hear expressions such as, “It’s been designed and built, yes, let’s have a bit of human factors at the end to say we’ve done it.”

4.4 Human Factors in an Engineering Based World
Unfortunately there remains a lack of penetration and understanding of the human factors discipline. Many well-established and accepted engineering based models for design and development neglect the importance of considering the human being and the organisation around them. In many cases it is difficult to present arguments within a predominantly mechanistic engineering environment. Human performance, capabilities and limitations, as well as wider organisational issues are too often seen as none essential parts in the design and development process. Even in cases where human factors engineering is included in the design process, it is not uncommon that the focus is limited, e.g., to safety critical systems or discrete parts of the design. Often the engineering dominated view is not able to see and appreciate the need for a comprehensive approach and analysis of the entire control centre. A typical example being when the design process is solely performed on paper in terms of specifications, and the only evaluations performed are technical reviews of these specifications. Possibly there is a physical mock-up built at the end of the design process where some tests are performed, this however, is normally far too late for efficient and effective human factors contributions.

4.5 Multi-Disciplinary Teams
Many sources advocate the use of a multi-disciplinary team within control centre design and upgrades. Such teams should typically include expertise from a range of disciplines such as human factors, different engineering domains, instrumentation and control, operations, computer science, physics, architecture, etc. Unfortunately not many companies employ human factors staff and it is expensive to hire consultants. This can lead to a resistance to use human factors expertise as it is perceived as too expensive.

4.6 End User Requirements
The importance of identifying end user requirements can often be seen by analysis of past incidents. Again unfortunately, the application of incident investigation techniques able to explore the role of human factors in such incidents are infrequent, and the ability to apply them correctly rarer still. Other indirect evidence of the importance of considering the end user can be seen from other markets. For example, the emphasis placed on user requirements and usability within the software and IT sectors, and the central role such factors are seen in providing a commercial advantage.

4.7 A Wider Organisational Perspective
Very often if human factors are considered there is a failure to not consider wider organisational attitudes, e.g., staffing level, crew structure, communications, authority, changing role of control centre and operators, etc.

4.8 Technology Driven Development
Many changes, or more correctly, most changes are driven by technology with the assumption that simple application of such technology will improve the operator’s situation. There is often little or no focus on the actual implications of introducing such technology on the functions in the control room and its influence on the role of the operators. The importance of a control centre philosophy, as described previously, in order to underpin any changes and to ensure a systematic and comprehensive consideration can therefore be seen.

4.9 Design Repeatability
Design repeatability relates to a pressure from vendors to sell ‘off the shelf solutions’ which makes it cheaper for the vendors who do not have to modify each control centre. Vendors can accept minor changes, but not substantial product re-designs. When vendors have had a design accepted and licensed they are unwilling to make changes which could lead to re-licensing requirements. This may result in utilities being pressured to accept an ‘off the peg’ rather than ‘bespoke’ control centre solution.
4.10 The Role of the Licensing Organisation

The importance of role of the regulatory/licensing organisation for a particular industry cannot be understated. In the nuclear industry for example, human factors issues have had to be addressed as regulators place more and more emphasis on the role of human performance and the need to adequately address these factors that affect that. The development of comprehensive regulations and guidelines such as NUREG 0711 and 0700 help to ensure that human factors are at least considered in a much more systematic fashion than before. Other industries are also beginning to appreciate the importance of regulatory requirements, for example, Halden is currently assisting the Norwegian Oil Directorate in developing a set of regulatory guidelines to be applied to offshore control room upgrades and new control rooms. The methodology is now in draft form and will be piloted by offshore inspectors during the remainder of the year 2000. One interesting aspect of this work is the relationship between the oil companies and the Directorate itself. Whilst it is acknowledged and accepted that it is the Directorate who place regulations and requirements on the industry, as in the case of the human factors requirements, they have been reviewed and commented on by the industry. This is because it is seen as essential to the success of the new requirements that industry agrees, at least in part, with the direction that the regulator is leading.

Other less regulated industries do not have this opportunity to direct industry and therefore often lack a systematic method for addressing these issues and consequently control centre changes can be a respond to either in-house, or industry specific incidents or accidents. For example the role of the train traffic control centres in the recent train accidents in Norway is bound to influence the policy of the newly established Railway Inspectorate in this area.

5. HOW TO IMPROVE THE SITUATION

When considering the issues mentioned in the section above one can start to wonder in what direction we should go to improve the situation, in order to influence the design and development process to the benefit of the end users. On one hand the engineering community needs to act more in terms of gaining a better understanding and appreciation of what human factors can contribute with and to seriously consider greater use of human factors expertise in design and development. However, an important element of the solution will require some self-criticism within the human factors community itself.

Criticism can be levelled at the human factors discipline itself as many of the techniques and methods advocated by guidelines, standards, handbooks and practitioners are not sufficiently complete or robust. The weaknesses in the way methods and techniques are structured, described, and not least, variations between practitioners who apply them, make it difficult for non-human factors specialists to appreciate the benefits and value of the methods and techniques. For example, techniques for functional analysis and allocation remain incomplete and present considerable problems in relation to understanding how they are carried out. The function allocation between the technical system and the human operator is probably one of the most difficult tasks in a design process, if it should be performed accurately, and is currently one of the weakest areas.

Improved human factors engineering methods and techniques means primarily that:

- The cost-benefit must be made more obvious.
- The cost in itself for using them must be reasonable.
- They cannot be allowed to be time consuming.
- They must be better described and validated.

In addition, they should of course be reliable and repeatable.

6. CONCLUSION

Aspects such as, absences of efficient human factors methods and cost, time constraints and limited appreciation of human factors are all aspects that could be better argued and countered if the human factors methods and techniques were better developed.

The other aspects discussed in the former sections except for design repeatability, would most probably be affected and the situation clearly improved if an integrated and comprehensive approach to
the design process, as described in the first part of the paper, was better understood and applied. In order to achieve that the human factors community has to improve the arguments, evidence and means of communicating the benefits and advantages of such an approach to design for industry. A better communicated design model together with enhanced human factors methods and techniques, will play an important role to improve the entire situation.

The design repeatability aspect would probably be affected to the better if the buyers, i.e., the utilities, were much stronger vis-à-vis the vendors.

It is our experience that many types of barriers still exist to the application and development of human factors across a broad range of industries. Not only are these barriers real but they do not occur singularly, rather within a particular industry it is a combination of factors that interact to hinder the wider acceptance and contribution of human factors. The challenges facing the human factors discipline in order to gain wider acceptance and influence are real and tangible and must be overcome if the discipline is to thrive. It is to be hoped that large scale accidents and loss of life will not continue to be the main driving force behind its wider acceptance and application.

7. REFERENCES