Applying Human Factors Engineering to Control Room Upgrade Projects and to the Design of New Build Control Rooms

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As well as similarities, there are some fundamental differences between ‘new build’ control room projects and control room ‘upgrades’, particularly in respect of the constraints which need to be overcome. The similarities and differences between the types of project are discussed in relation to the impact on the human element in design. Regardless of the type of project, or its particular set of constraints, there remains an opportunity to optimise the human performance within the system by applying the principles of a human centred design approach. The human centred design approach is outlined and examples are used to illustrate key points and achievements that have been made in practice. The paper presents a practitioner’s view based on 21 years of experience across a range of industries. The purpose of the paper is to encourage current and future control room project teams to consider an effective approach to integrate human factors engineering within design.

Introduction

Control room operations are typically critical to safe operation. The fundamental and primary purpose of human factors applied to control suites is to facilitate reliable, effective and efficient human performance. The control system interface must enable the operator to monitor and control information effectively. The control building layout needs to support effective person to person interactions. All elements of the working environment need to avoid negative performance shaping factors which increase the potential for human failure.

The most widely used and endorsed standard for applying Human Factors Engineering (HFE) to the design of control centres is the international standard, ISO 11064, Parts 1 to 7, 2000 to 2013. Similarly, company and industry based standards are also emerging to ensure that the human aspects of design meet relevant minimum criteria and are sufficiently integrated within the design process. The ISO standard states that it is applicable to the design of (new) control centres, as well as to the expansion, refurbishment and upgrade of control centres. Regardless of the type of project, there are considerable benefits to be gained from applying these standards.

A human centred design process is generally advocated. Colloquially, this means ‘designing from the ‘human’ out’. It is fairly intuitive to think that achieving an ergonomic design is easier when applied to new build projects, as there are fewer constraints. For example, space envelopes can be determined for a ‘new’ build by understanding the number of people, nature of their tasks and interaction requirements. For an existing facility, space is often a given constraint and the operation has to fit within that space. For the most part, it is indeed the case that there are fewer practical constraints for new build projects. However, new build projects are not without their constraints and these inevitably will also impact on the human aspects of the design.

This paper outlines what a human centred design approach means in practice and how different HFE tools and techniques can be used at various stages of the design process. Some of the similarities and differences between different types of project are discussed, but in both cases, the human centred design approach is advocated to achieve successful operational performance. The discussion draws on experience of applying HFE to control room design within upstream, midstream and downstream oil and gas process control rooms, railway station and line control, emergency services and shipping. Some of the experience pre-dates the existence of any specific HFE standards for control centres, but have still used core HFE principles and the human centred design approach.

Project Types

New build control room projects vary in scope and size, from a complete new site with no existing facilities to an existing site requiring a new control building. The operational aspects of these facilities will vary in their level of definition and understanding, particularly in the early stages of a project, such that the operation is likely to be clearer for the facility which currently exists.

Control room upgrades also vary in scope and size. This can include moving the control room operation to an alternative building or space through to making changes to the structure and / or fabric of an existing control room. It may just mean adding new control system equipment within the existing facility. In these instances, the control operations are likely to be well established, although changes to that operation may be part of the project scope.

Design Constraints and the Impact on the Human Element

There are a large range of design constraints which cannot be exhaustively explored within this paper, and particular constraints may exist for specific projects. The constraints discussed are examples gleaned from previous experience and are outlined to provide examples of how design constraints impact on the human element.

Control Room Location

With a new build, there is an opportunity to consider whether the control room operation is better performed remotely or in the process or activity location. There are advantages to be gained from being proximal to the process or activity, particularly facilitation of information transfer and collaborative decision making between the control room personnel and outside operators. There may be other advantages, such as having direct visibility and access to the actual activity or conversely easy access to control screens for the outside operators. The advantage of being remote could be that those who are in the primary position of control are removed from a hazardous area and can remain capable of bringing a major incident under control. This is an important consideration, but typically it is not an opportunity for most control room upgrades. Even for new builds, the control room location may be dictated by a range of different factors, including competition for site real estate.

Space

Existing facilities are often constrained by the existing structure, shape and size of the building. Space constraints can be caused by restricted floor area, inadequate vertical space, unusable space, and immovable equipment, such as existing Emergency Shutdown cabinets. This presents particular constraints to the number of people who can be comfortably (and efficiently) accommodated, the effectiveness of the control room layout, the equipment layout, the auditory environment, lighting layout and even the thermal environment. New builds may also be space-constrained as cost increases with an increase in building size.

Architectural / Structural Features

Architectural and structural features, such as windows, doors and supporting members can present issues related to control room layout, the facilitation of person to person interactions, achieving an optimal lighting layout, and circulation and traffic flow.

Control Equipment Interfaces

The Human Machine Interface (HMI), which includes hardware and software, is one of the key determinants of human performance in this type of work setting. The control room operator suffered some real challenges during the implementation of the digital era due to a lack of focus on the needs of the operator, rather than the technology itself. There have been improvements in HMI design in more recent years, but there are still numerous opportunities for further advancement. One additional challenge is the introduction of new systems running alongside existing older systems. New systems, even if they have a better HMI, may be inconsistent with older systems. This means that the control room operator needs to adjust his or her mental model each time they interact with each system. This is at best tiring, but at worst leads to human error.

Heating, Air Conditioning and Ventilation (HVAC)

HVAC systems can often be too expensive or disruptive to change, but the downside of not upgrading the HVAC is that it may have to perform a function for which it was not originally designed. This can lead to a poor thermal environment and reduce operator performance and comfort.

Operational Aspects

A frequent challenge that exists relates to the impact of decisions about manning and workload. Either, reducing the number of personnel or increasing / changing the work scope can impact on the ability of an individual to perform effectively. It is important to consider, and even test, the manning requirement for all relevant operational scenarios, such as normal operations (steady state), abnormal events (such as plant upsets), emergency scenarios, start-up and shutdown, handover, commissioning and so on. All such scenarios present different requirements which need to be accommodated, and if they are overlooked, can significantly impact the resulting operational performance.

Transitioning to a new control room is also a common challenge for any type of control room project, but especially if the control operation remains ongoing as the transition takes place. Risks to human performance can sometimes be poorly considered.

Whatever the nature of the project, there will always be constraints and challenges that need to be navigated during the design process, some projects more than others. Regardless of the type of project or the constraints faced, design trade-offs will be necessary, but it is essential to ensure that the human element is adequately considered. Failing to give adequate consideration to the human element raises the risk of compromising the human, and subsequently overall, system safety and performance.

Human Centred Design Process

There are a number of standards and models available which advocate a human centred design process, such as ISO 6385, 2004, ISO 11064, 2000 to 2013, and ISO 9241-210, 2014, all of which are applicable to control room projects. Effectively they contain the following basic iterative steps, as illustrated in Figure 1:

1. Understand and specify the context of use, such as who the users are, the tasks they needs to undertake and how, and the work environment under which the tasks must be performed;

2. Define the requirements which need to be met during design, based on analysis of the context of use and the design criteria set within standards;
3. Undertake design activity to meet the user requirements, including assessing the human impact during design trade-offs;
4. Evaluate the design to ensure that the user requirements have been met and that the design meets the needs of the end users.

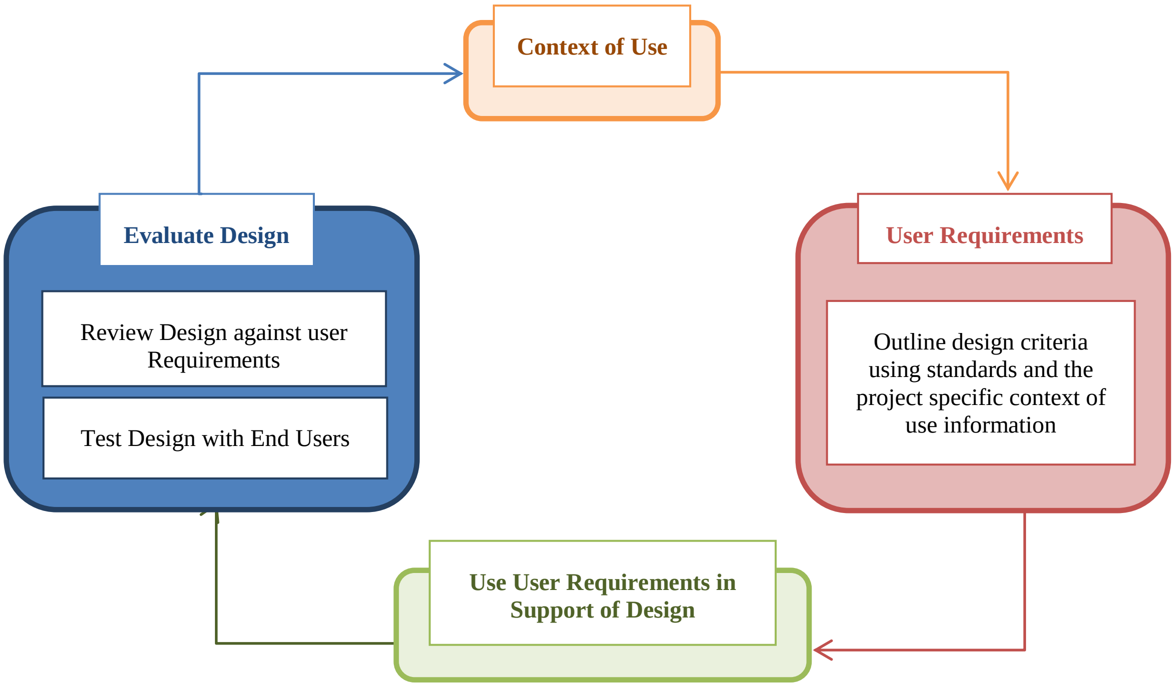


Figure 1 - General Overview of a Human Centred Design Process

ISO 11064 defines the process in five phases:

A. Clarification: define the project purpose, background context, constraints and any other relevant information;
B. Analysis and Definition: analyse the human elements, including the functions, tasks, roles, and interactions;
C. Concept Design: develop initial designs for the building, control room, furniture, HMI and so on;
D. Detailed Design: develop detailed design specifications to support construction and procurement, including the necessary criteria which must be met;
E. Operational Feedback: review design post-commissioning to support lessons learned.

The standards (not just ISO 11064) also advocate three additional and important principles:

- Integrate ergonomics within engineering practice and the project management process from the start of the project and ensure it continues throughout;
- Incorporate end user participation in a structured manner throughout the design process;
- Implement the process using an inter-disciplinary team which includes disciplines such as; ergonomics, engineering, architecture, and industrial design. The combined skill and knowledge enable a more optimal design to be achieved.

The Use of HFE Tools and Techniques

A fundamental step in the process is the analysis and definition of the context of use, and the following steps are examples of how this is undertaken and used in practice. This is an illustrative, rather than comprehensive overview.

The illustrations within this section are not actual project specific examples, but have been created on the basis of project examples from a well-established multi-disciplinary team which specialises in control room design. The team is headed up by Brad Adams Walker Architecture, PC based in Denver, USA and includes architects, ergonomists, engineers (structural, civil, mechanical, electrical, acoustic), interior designers, lighting designers and landscape architects.

Analyses to Derive the Building Layout

The functions which need to be undertaken within the control suite are identified to establish different work areas that the building needs to accommodate. The roles and numbers of personnel needing to be involved in the performance of these functions are analysed. This may include a definition of the allocation of functions to roles and / or the degree of automation.

Once the functions, functional allocation and roles and numbers have been established, the work areas are defined and appropriate area sizes calculated. The work areas are then reviewed to identify the degree of adjacency required between work areas. This is undertaken using an adjacency matrix, as illustrated in Figure 2 and depicts the degree of adjacency required between different work areas. It is typically undertaken in a workshop setting and may include HFE, architecture and end user involvement. The adjacency matrix is then translated into a functional adjacency diagram, as illustrated in Figure 3.

0	Neutral - Adjacency
1	Preferred Adjacency
2	Required Adjacency

	Reception/Security	**Permit Office**	**Break Room**	**Shower / toilet**	**Production Supr Office**	**Senior Operator Office**	**Field Op Area**	**Meeting Room**	**Training Room**	**Services Areas**	**Control Room**	**CCR Toilet**	**File / library**	**Copy/Fax Room**	**Exercise Room**	**Alertness Recovery**
Reception/Security																
Permit Office	0															
Break Room	0	0														
Shower / toilet	1	0	1													
Production Supr Office	1	0	0	0												
Senior Operator Office	0	1	0	0	0											
Field Op Area	0	1	0	0	0	1										
Meeting Room	1	0	0	1	0	0	0									
Training Room	0	0	0	0	0	0	0	0								
Services Areas	0	0	0	0	0	0	0	0	0							
Control Room	0	2	2	0	2	2	2	2	1	0						
CCR Toilet	0	0	0	0	0	0	0	0	0	0	2					
File / library	0	0	0	0	0	0	0	0	0	0	0	0				
Copy/Fax Room	0	1	0	0	0	1	0	0	0	0	0	0	0			
Exercise Room	0	0	0	0	0	0	0	0	0	0	2	0	0	0		
Alertness Recovery	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	

Figure 2 - Illustration of an Adjacency Matrix

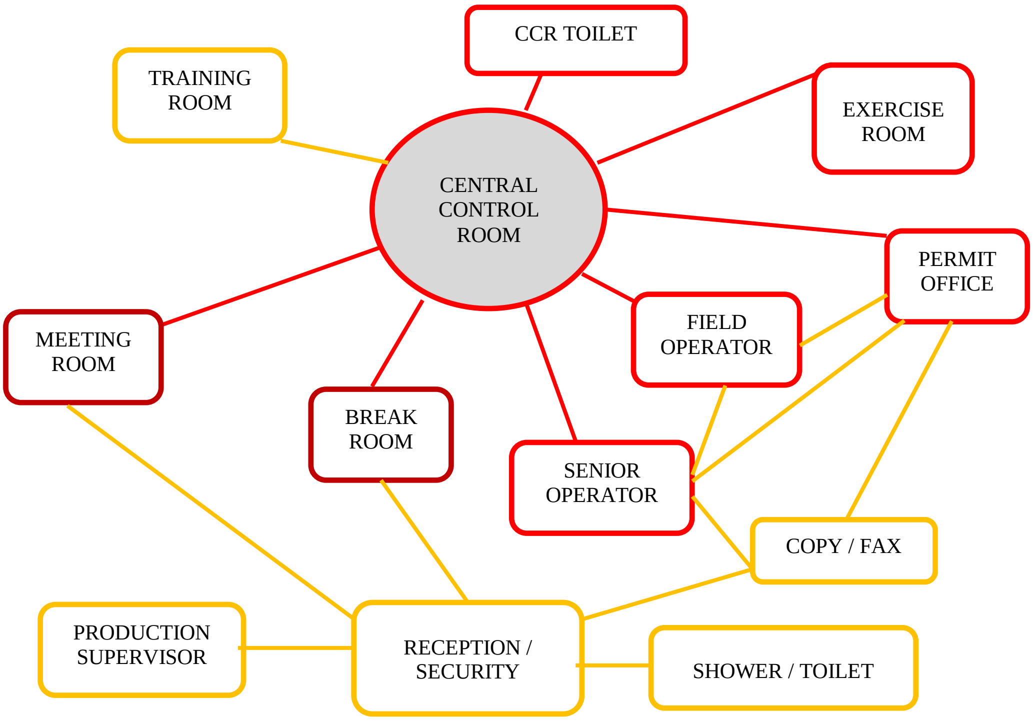


Figure 3 - Illustration of a Functional Adjacency Diagram

The functional adjacency diagram is used to aid the development of the schematic design, as illustrated in the block diagram in Figure 4. Presenting the adjacency diagram and block plan provides a good feedback and review opportunity with different disciplines and end users prior to developing the schematic floor plans and subsequent furniture plans.

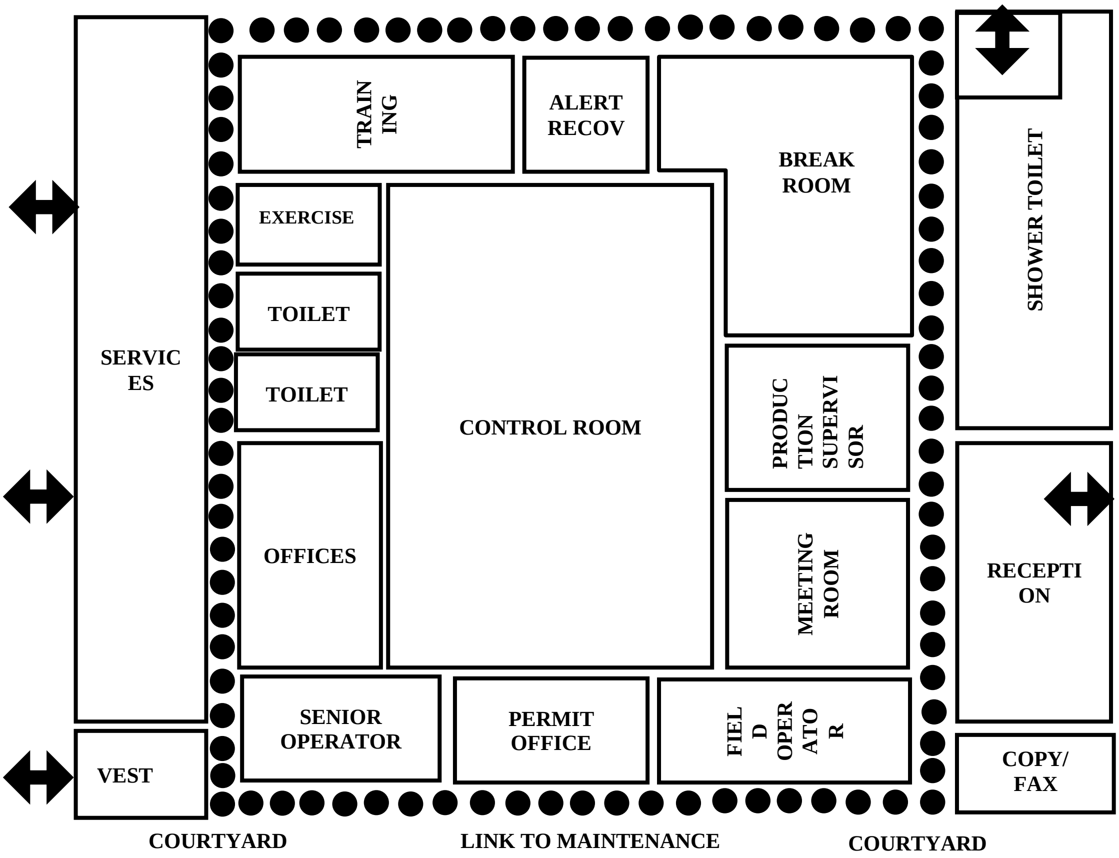
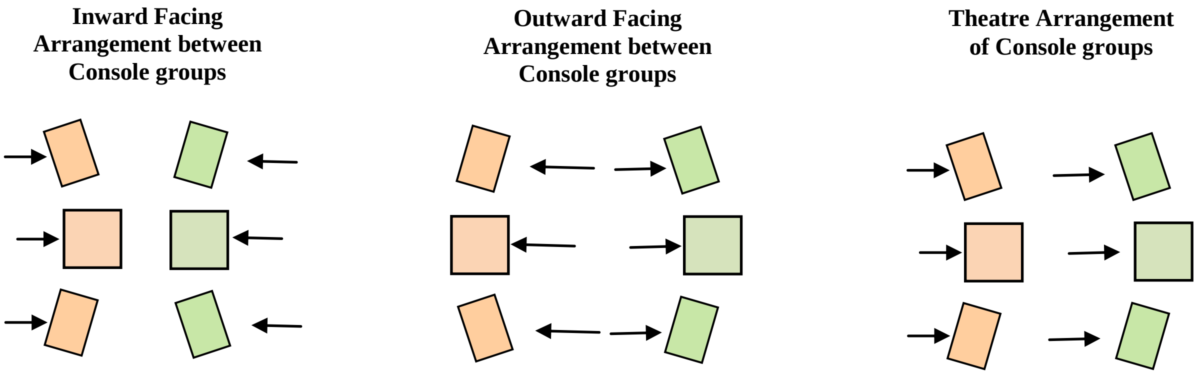


Figure 4 - Illustration of a Block Plan

Analyses to Derive the Control Room Layout

The control room layout is derived on the basis of the interactions that need to be accommodated within that space. This will include person to person interactions and person to equipment interactions and these can be determined using different task and link analysis techniques. Using person to person link analysis as an example, the interactions required between each role are identified and rated using a simple scale. This is undertaken for roles based in the control room, those based in other areas of the control suite, and those who need to interact with roles in the control room, but normally reside outside of the control suite. This information is then used to determine control layout options, such that the higher the frequency / importance of the interactions, the greater the priority for co-location (assuming that it is face to face communication that is required). It is important that the analyses are undertaken for different operational scenarios, such as normal operations (steady state), abnormal events (such as plant upsets), emergency scenarios, so that the layout is suitable for all scenarios.

Console orientation is an important consideration to support control room interactions. Key considerations include the need for equipment sharing, face to face communication, supervision of operators, maintenance access and the avoidance of noise disturbance. Examples of different console groupings and orientations are shown in Figure 5.



Inward Facing Arrangement between Console groups

Outward Facing Arrangement between Console groups

Theatre Arrangement of Console groups

Figure 5 - Examples of Different Console Orientations

Control room layouts often use a variety or hybrid of console orientations to achieve the interaction needs. The role to equipment analysis will also be used in support of the console layout.

Case Studies

A small sample of case studies is reviewed within this section. The discussion cannot be regarded as a scientifically valid cross comparison between the different projects as they were undertaken in different industries, used different standards, the involvement was at different stages, and they had different project scopes. For example, some projects included the control system elements but little on the building fabric, whereas others included a much wider scope. The case studies are used to anecdotally illustrate some of the key points being made within this paper. The case studies refer to a 'level of compliance' measurement which is based on an HFE review of the design against the derived set of HFE requirements for that project. Results of user trials or other types of evaluation have not been included in the discussion. A summary of the case study examples is shown in Table 1 which provides an overview of the project type, the scale of each control room and which stage(s) of the design included HFE involvement.

No.	Project Type	Industry	Project Stage(s) including HFE involvement	Number of Control Areas	Maximum Control Room Occupancy / No. of Consoles	Level of HFE Compliance
1	New build	Onshore oil & gas	Start to 100%	17	32	96%
2	New build	Onshore LNG Plant	Up to 30% so far	5	10	65%
3	Upgrade	Emergency Services	Start to post 100%	5	52	78%
4	Upgrade	Emergency Services	Post design	10	52	50%
5	Upgrade	Offshore oil & gas	Concept & detailed design	4 fields	2	48%
6	Upgrade	Offshore oil & gas	End of design	5 fields	3	25%

Table 1 - Summary of Case Studies

Case Study 1 - Onshore Oil and Gas Plant (New Build)

The first example was a new build control building project for an existing onshore oil and gas plant in the 'old' Russia region. There had been HFE involvement from the early conceptual stage and there was participation of end users within the human factors design process, including during the analyses, conceptual design development, design reviews and user trials. The design process was led by the architectural team and there was cross-disciplinary involvement from HFE, architecture, engineering and interior design. HFE compliance was measured against ISO11064 at each of the critical design stages of 30%, 60%, 90% and 100%. By the 100% design stage, the project had achieved 96% compliance with 2% partial or non-compliance. The key area of compromise was that the floor reflectance level could not be achieved with the selected carpet tiles which were the preferred option given their durability, noise absorption benefit and low likelihood of 'showing' dirt.

In summary, this was a project which exemplifies the achievements that can be made with an effective human centred design process, with integration of the right disciplines and end users.

Case Study 2 - Onshore Liquefied Natural Gas Plant (New Build)

The second example was a new build control building being designed as part of a completely new site in Canada. The project is currently just past the 30% design stage and has had significant HFE involvement from the start. A comprehensive human factors design process has been followed and the multi-disciplinary team had included end user participation during the analyses, conceptual design development and conceptual design reviews. The design process was again led by the architectural team and there was cross-disciplinary involvement from HFE, architecture, engineering and interior design. HFE compliance was measured against the client's internal standard for control centres. By the 30% design stage, the project had achieved 65% compliance with 26% 'unknowns' and 3% partial or non-compliance. The key areas which require resolution are the console size and elements of the HMI integration within the console design. These do not present particular challenges and will be overcome during the next stage.

In summary, this was also a project which exemplifies the achievements that can be made with an effective human centred design process, with good inter-disciplinary and end user integration.

Case Study 3 - Emergency Services (Control Room Upgrade)

The third example was a move of an emergency services control room to an existing asset which needed to be modified to accommodate the control room operation. This was in the Midlands area of the UK. The project team embraced the HFE involvement due to having gained lessons learned from HFE reviews and HFE involvement in the previous upgrade of the existing control room. There was comprehensive end user participation during the analyses, design development, design reviews and user trial. HFE compliance was measured against ISO 11064 at the end of the design phase and there was also a review during construction. By the 100% design stage, the project had achieved 78% compliance with 15% partial or non-compliance. The key areas of compromise were as a result of constraints related to using an existing asset, including restricted floor to ceiling height, floor space at maximum occupancy, and the presence of structural pillars.

In summary, this was a project which benefited from incorporating HFE, despite some aspects of the design not being ideal.

Case Study 4 - Emergency Services (Control Room Upgrade)

The fourth example was a move of the emergency services control room to another room within the same existing building. There was resistance from the project team to embrace HFE and the HFE involvement was limited to a review of the design once construction had commenced. There was some end user participation to enable the operation to be understood. HFE compliance was measured against ISO 11064, achieving 50% compliance with 19% partial or non-compliance, and several outstanding 'unknowns'. The key areas of compromise were partially related to the constraints of using an existing asset, including restricted floor to ceiling height, but there were also issues related to poor circulation routes, poor functional layout, noise issues and non-optimal lighting arrangements.

In summary, this project exemplified the problems of not incorporating HFE effectively or in a timely manner. Several follow on reviews were undertaken during the operations phase to try and mitigate the issues that the operators were experiencing.

Case Study 5 - Offshore Oil and Gas (Control Room Upgrade)

The fifth example was a control room upgrade of an existing offshore platform. There was acceptance from the project team that HFE was required, and it was included from a fairly early point within the design cycle. There was reasonable integration of HFE with some other disciplines during certain activities and there was end user participation during the analyses, and the control room layout design and review. HFE compliance was measured during detailed design against ISO 11064, and the company's own control room standard, achieving 48% compliance with 4% partial or non-compliance, and several outstanding 'unknowns', so there is still a need to complete the HFE effort. The key areas of compromise were mostly related to the constraints of using an existing asset, including restricted space which was also impacted by the need to accommodate obsolete and new systems during the transition and future operation.

In summary, this project did show some considerable benefits in the resulting control room layout design which was innovative given the constraints being faced. The project would have benefited from more consistent integration of the HFE effort with other disciplines across the project.

Case Study 6 - Offshore Oil and Gas (Control Room Upgrade)

The final example was a control room upgrade of an existing offshore platform as a result of additional modules and control systems being added to the platform. There was resistance from the project team to embrace HFE, and it was included rather late within the design cycle. There was little integration of HFE with other disciplines and difficulties were experienced gaining end user participation. HFE compliance was measured towards the end of detailed design against ISO 11064, achieving 25% compliance with 5% partial or non-compliance, and several outstanding 'unknowns'. The key areas of compromise were operator sightlines, operator workload and the integration of the HMI.

In summary, for this project some substantial concerns were reported. The project would have greatly benefited from a human centred design approach.

Conclusions

New build control rooms often have fewer constraints than control room upgrades, but this is not always the case as new build projects can also face considerable constraints. New builds can also typically achieve a higher 'ergonomic' standard if a human centred design approach is used, but the success of the human factors input is often a factor of whether early involvement and effective integration is achieved.

Even though there are often more constraints for control room upgrades, there are always opportunities to improve design and realise improved performance of the human element, and subsequently overall system performance.

The fundamental elements for achieving a successful ergonomic design are:

- Using a human centred design process, commencing at an early design stage
- Engaging the right professional disciplines in a collaborative and integrated team approach
- Undertaking comprehensive analyses of the context of use and end user requirements to provide the baseline for what the control room needs to achieve
- Engaging structured and timely end user participation as an element of the human centred design process
- Using an iterative approach

References

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