IPTC-11762-PP

Improvement of Human Factors in Control Centre Design - Experiences Using ISO 11064 In The Norwegian Petroleum Industry And Suggestions For Improvements

Andreas Lumbe Aas, NTNU Dept of Computer Science; Stig Ole Johnsen, Sintef Technology and Society

Abstract

Managing Human Factors (HF) in the design of control centres (CC) has become increasingly important in large-scale petroleum projects, because of the impact it has on safety and efficient operations. Integrated Operations (IO) and the "e-field of the future" introduce new ways of working, allowing for virtual teams but raise new risk management issues. In 2006, 22 persons, representing different sectors and actors in the industry were asked about their experiences with ISO 11064. ISO 11064 is the standard "Ergonomic design of control centres" and provides guidance on how to handle HF during design of CC.

This paper presents the present status; summarizing experiences made when applying ISO 11064 in Norwegian petroleum projects and suggest areas of improvements. The purpose of the study has been to assess and improve the standard's usefulness for the purpose of reducing the risks introduced by bad design, and to create new guidelines where such are found necessary.

Results indicate that ISO 11064 contributes positively to structuring and legitimating the HF work. The interdisciplinary approach has proved to be an effective HF risk management tool. Applying the standard gives safer operations; this will reduce risk and allow for increased operative efficiency. However, the study also indicates possibilities of improvement of ISO 11064 in areas such as scope of the standard, organizational issues, work procedures, competence in design and operations, exception handling in a virtual organization, communication to the engineering team and documentation of design results. Thus, additional guidelines and techniques are necessary when designing and managing HF in modern CC.

Several improvements to ISO 11064 are suggested. In particular, a goal-based approach can ensure the standard's future applicability, while accommodating technological changes. A survey is planned to follow up on the results to elaborate the findings in the study.

1. Introduction

"*HF (ergonomics) is the scientific discipline concerned with the understanding of interactions among human and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance*" [1]. The main objective of this exploratory study is to map experiences from applying ISO 11064 to CC design in full scale industrial projects, e.g. construction of new offshore installations (oil platforms, FPSOs[1]) and onshore process installations as well as major CC modifications of the same.

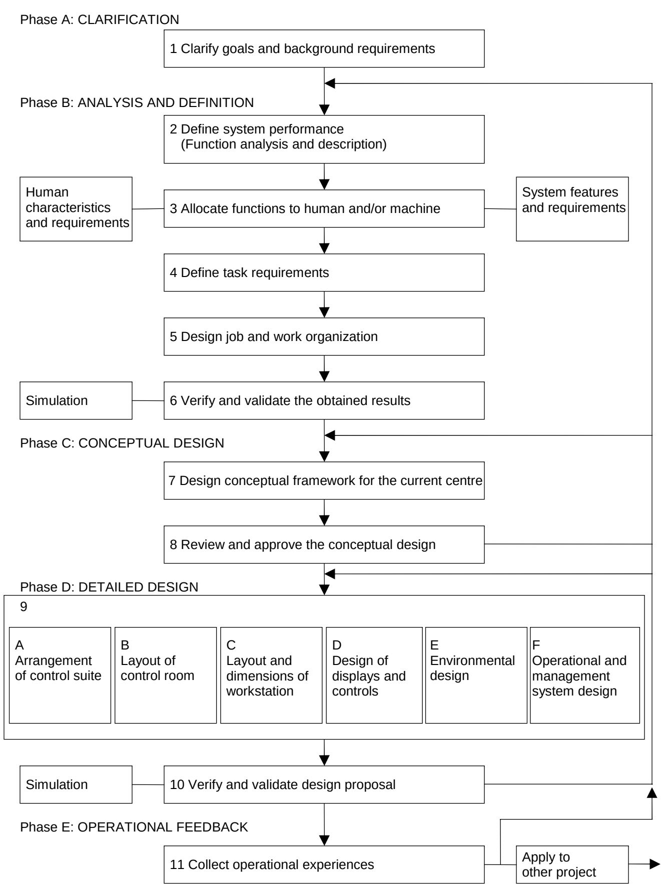

Figure 1. Ergonomic design process for control centres [2].

[1] Floating Production, Storage and Offtake.

Figure 1 shows the ergonomic design process for CC in ISO 11064. This process is divided into five phases, from A to E and shall be performed iteratively. Time, available resources technical information and a host of other factors restricts the ergonomist from doing the steps in a single sweep [3]. See ISO 11064-1 for further details. ISO 11064 consists of seven parts, where part five is still in draft. This paper focus mainly on part one, principles for the design of control centres, as this was the most commonly used among the interviewees. Several interviewees pointed out that part three: control room layout [4] and part seven: principles for the evaluation of control centres [5] were important as well.

ISO 11064 is a normative reference in the "Regulations relating to design and outfitting of facilities etc. in the petroleum activities (The facilities regulations)" published by the Petroleum Safety Authority Norway (PSA), the Norwegian Pollution Control Authority (SFT) and the Norwegian Social and Health Directorate (NSHD). The guidelines to the facilities regulations state in section 20 that "*The ISO 11064 standard should be used for design of the central control room*" [6]. ISO 11064 is not specifically designed for IO, but the principles of the standard can be used also for IO.

The facilities regulations are to be followed in design and modifications of offshore installations. Hence, ISO 11064 has been used in several major projects over the last years. However, there has been no systemized cross-company mapping of the experiences made. Little literature is available regarding the practical use of ISO 11064 and no literature was found covering the experiences of an entire industrial sector.

The study also includes mapping of experiences with the CRIOP [7] method, that has been adapted to ISO 11064. The CRIOP methodology is used to *"verify and validate the ability of a control centre to safely and effectively handle all modes of operations including start up, normal operations, maintenance and revision maintenance, process disturbances, safety critical situations and shut down*" [8]. The CRIOP methodology can be used for verification and validation (V&V) of the application of ISO 11064, and contains some 'best practice' guidelines from the industry and the method is used by the major oil companies in Norway.

The systematic consideration of human error in systems designs can lead to improved safety, an indeed improved productivity in many cases [9]. To allow for efficient design of safety critical systems, it's important to have flexible safety standards that give good cost/benefit and contributes to the design of safer systems. A goal-based approach will be discussed for this purpose.

2. Materials and Methods

This paper is based on semi-structured interviews with persons from the Norwegian petroleum industry. Due to the exploratory nature of this study, the interviews were open-ended [10]. 22 persons were interviewed and approximately 90% of the interviewees are experienced or highly experienced in their field, i.e. more than 5 years of experience. The interviewees were selected using convenience sampling and snowballing.

An interview guide was prepared and checked by walkthrough before the interviews started. This guide was used for all interviews, with some variations depending on the type of actor being interviewed. The majority of the interviews lasted between 60 and 90 minutes. Notes were taken during each interview, and when recording was allowed by the participant(s), this was used to complete the notes after each interview.

The interviewees represent different types of actors. These are operator companies, engineering companies, HF-consultants, authorities and Central Control Room (CCR) operators (i.e. end users). Figure 2 shows an overview of the different types of actors who participated in the study.

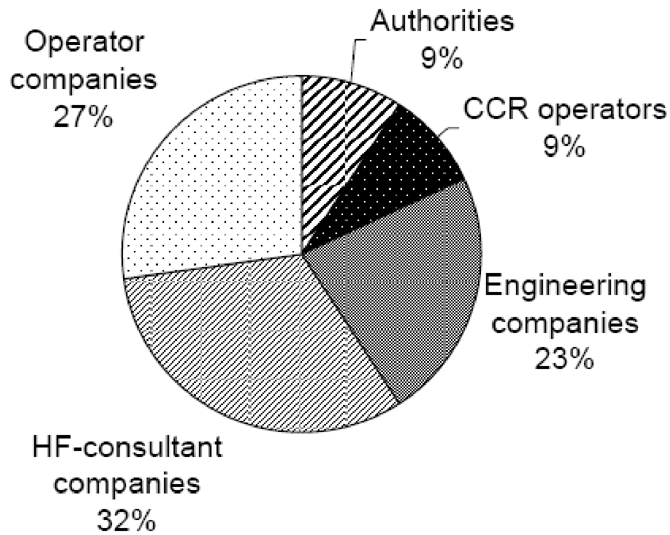

Figure 2. Type of actors participating in the study.

Operator companies, HF-consultants and engineering companies are 82% of the interviewees. These have most influence on the processes of ISO 11064, as they are directly involved in the design process. The authorities (PSA[2]) carry out audits to ensure that the requirements of ISO 11064 (and a number of other rules and regulations) are fulfilled. CCR operators represent the end users participating in the development process and thereby indirectly influencing the CC design. Some companies have their own design procedures incorporating the principles of ISO 11064.

The remainder of this paper is structured as follows: Part 3 outlines the most important findings, part 4 discusses these findings and suggests possible improvements and part 5 summarizes the findings and outlines the future work.

3. Results

The results presented are the summarized opinions and experiences of the participants in the study. They are not the opinions of the authors. Even though they are collected, interpreted, summarized and reproduced by the authors, objectivity has been maintained during the entire process. When the authors have made their own observations, this is clearly stated in the text. Only the main findings are presented, i.e. where the majority of all participants share similar views.

[2] Petroleum Safety Authority Norway

3.1 ISO 11064 - Identified strengths. This part describes the identified main positive contributions from applying ISO 11064.

3.1.1 Structure and legitimate HF work. The standard gives a good and structured methodology for the process of CC design. **Many participants emphasized the need to pragmatically adapt the process described in the standard to each project.** Nevertheless, most participants agreed that the process described in the standard's part one gives a reasonable overview of the phases and thus provides a framework in which to conduct the required HF activities. The standard requires that decisions are documented, enabling tracking of decisions and the background for making them.

Having an international standard legitimates and recognizes the importance of the HF work. ISO 11064 is a normative reference in the Norwegian rules and regulations for this industrial sector [6]. It should be noted that a few of the participants considered this a weakness due to the extent of requirements in the standard.

3.1.2 Interdisciplinary design team. Part 1 of ISO 11064 contains nine principles of ergonomic design. Principle number eight is "Form an interdisciplinary design team" [2]. The interdisciplinary design team is considered to be a very effective tool in the design process. The team implementation varies depending on the type and size of a project, resources available, project complexity etc, but there is often a HF expert facilitating the group. If the facilitator is not an HF expert, he or she is usually from the Health, Safety and Environment (HSE) discipline. Disciplines participating in the interdisciplinary design team can be, but are not limited to, instrumentation and automation, operations (including experienced CC operators), occupational health and safety, architect, telecom, and HF.

When the facilitator of the interdisciplinary design team is a HF expert, it was noted that it's important that he or she has a good understanding of the project's technical and organizational aspects, oil and gas operations and is able to communicate effectively with the rest of the team. This includes understanding the technical terms.

3.1.3 Results are followed up. The results from the interdisciplinary design team are recommendations, since the team normally has no formal mandate to make decisions. The responsibility for carrying through the recommendations is resting at the respective disciplines themselves. However, most of the recommendations are followed up, as long as they are reasonably practicable and it's not too late to implement them.

3.2 ISO 11064 - Identified weaknesses. In line with the focus of the interviews, the interviewees pointed out numerous weaknesses of ISO 11064. These weaknesses originate from the standard itself or from its application.

3.2.1 Scope of ISO 11064. ISO 11064 is concerned with the design of CCs. The definition of a CC is "*combination of control rooms, control suites and local control stations which are functionally related and all on the same site*" [4]. This definition may conflict with the ideas behind IO. IO use ICT (Information and Communications Technology) to operate oil fields in new and innovative ways using a network of collaborating actors. IO may lead to remote support or remote control and remote operations of platforms offshore. Issues such as responsibility, communication, command and control is increasingly important in such a network.

The standard's focus on CCs was especially pointed out by interviewees involved in drilling. ISO 11064 shall be applied to the design of the driller's cabin [11]. ISO 11064 was reported to be less suitable for small control units (e.g. driller's cabin) and gave poor results compared to the resources spent, but use of HF techniques is recommended.

Using ISO 11064 for CC modification was reported (at least in some cases) to be more challenging than for new CC designs. ISO 11064 more or less assumes that the CC is designed from scratch, but when making changes to an existing design, many parameters are preset and can not be changed.

Most interviewees point out that part 1 of ISO 11064 is the most widely used part because it describes the overall design process. The nine principles of ergonomic design described in this part are mentioned by only a few.

3.2.2 Organizational issues within the CC. ISO 11064 is concerned with the organization of work within the CC being designed. The authors observe that the standard does not deal with challenges related to onshore CCs for remote support or operations, IO or virtual organizations.

In a setting where IO is used, control may be distributed between several facilities such as Control rooms offshore, the Operators onshore operation centre, the Service Company's onshore operations centre, External experts in a collaboration room and general remote collaborations rooms. See figure 3.

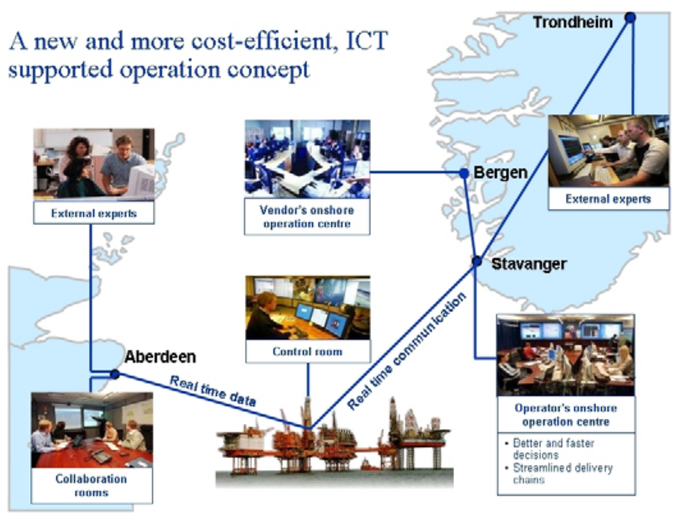

Figure 3. Key actors involved in IO [12].

These facilities are used to improve remote support, remote monitoring or remote control of platforms offshore and HF issues are very important in the design of all these facilities, especially since the control may be distributed in this network.

This network seems to constitute a virtual organization. A Virtual Organization is often defined as a group of people from different organizations located at different geographical locations working together in shared interdependent processes to achieve shared objectives within a defined timeframe. The authority and roles/responsibility of the participants are clearly defined. The collaboration is supported by technology that gives the participants common understanding and enables good cooperation among the participants.

This is related to the definition of CC described in part 3.2.1 and our opinion is that the standard should support IO and virtual organizations and the use of distributed control centres and collaboration rooms, to help improve and guide HF in these new settings.

3.2.3 Organizational issues in the project. The processes of ISO 11064 were said to be 'out of sync' with the rest of the project. By this, the participants meant that the design process outlined in figure 1 does not match the processes of industrial projects. There is a mismatch between the actual needs at the different project stages and the activities described in the standard. However, many of the participants pointed out that this was solved by adapting the use of the standard to each project. When ISO 11064 is applied in a project it needs to be interpreted in the context of use in order to be effective. Several of the participants found the standard to be unclear and ambiguous and therefore hard to interpret in the context of specific projects. Others found this to be only a minor challenge or no problem at all.

The way large industrial projects are executed in the Norwegian petroleum sector (and probably also in other industrial sectors in other countries) implies that the personnel that are to operate the facilities are not employed before the facilities are under construction. Hence, there are few or no 'real users' available in the early phases of a project. Participants pointed out that this is solved by using personnel from similar systems if they exist.

Earlier, there were some problems due to the standard being taken into account too late in projects. This has improved significantly and the HF competence is now usually included in the Front End Engineering and Design (FEED) phase. This is a great step forward from earlier projects, when HF competence was introduced in the detailed design. Then it was too late to make any major changes to the system, due to the time and cost of changes after design freeze.

3.2.4 Competence requirements. The success of the design and the design process depends (heavily) on individuals. The person responsible for HF must take HF issues into account wherever necessary and in due time, to not risk others involved seeing HF issues as imposed activities that just slows the project. It was pointed out by several of the participants that a successful HF design was depending significantly more on the person responsible for HF, timing and scope defined by the project than on ISO 11064. It seems important to have resources with HF competence, project competence and communication skills available as early as possible in the design project. The design of a CC, especially when IO is involved can be a challenging project, involving changes in organization, working procedures and use of technology.

3.2.5 Work organization and procedures. The number of operators in CC is often decided early in a project. I.e. before the analyses required by ISO 11064 are conducted. (See step 5 in figure 1). The selection of control systems, SAS (Safety and Automation System), can also be done before these analyses are completed and for other reasons than HF issues. The authors observe that the definition of CC discussed in part 3.2.1 is unsuitable for the design of work systems for IO and virtual organizations.

3.2.6 Documentation. Documentation of the HF-work can become 'overwhelming' and challenges related to the readability of the documentation were reported. E.g. it can be hard to separate important issues from less important ones. Some of the interviewees said that this was a problem, while others said it was not.

The form of the results was also mentioned. Several participants said that the HF work should ideally give more concrete results, such as screen layouts, prototypes etc.

3.2.7 Experiences from similar CCs. The study shows that it's common practice to do a systematic review of similar designs/projects if they exist. Experiences from similar projects are gathered at start-up of a new project and implemented into the new project. For some new and innovative projects, this was not possible, at least not for all aspects. Several of the interviewees pointed out that the gathering of operational experience be stated more clearly in the standard, i.e. incorporated in the figure of the design process (see figure 1).

3.3 CRIOP - Identified strengths and weaknesses. The participants were asked about CRIOP. The majority of the participants had at least some knowledge of both CRIOP 1 (checklists) and with the CRIOP scenario analyses. It's important to point out that there were differences in opinion of the usefulness of CRIOP.

CRIOP is conducted in a meeting or workshop with a number of expert participants and a leader or facilitator. It's crucial that the facilitator has knowledge of the domain being analysed as well as knowing how to conduct a CRIOP workshop.

Most participants meant that the checklists were suitable only for 'self evaluation', i.e. using the checklists themselves to verify that they had covered all relevant HF-aspects in a design solution. Others meant that they were good for workshops as well. However, the checklists need to be adapted to the project type and current project phase in order to be used effectively.

The scenario analysis can give useful results. Some participants consider this to be a validation of the design, while others strongly disagree to that. Most participants find that the scenarios, if they are well thought out and well prepared, give useful information about the validity of the design.

CRIOP has been chosen as a standard on the Norwegian continental shelf by several large operators, and is used internationally. CRIOP is continuously improved based on input from the industry and can be seen as a good practice tool related to validation and verification activities as mentioned in ISO 11064.

4. Discussion

Several strengths of ISO 11064 were identified, but since the main focus in this paper is to identify weaknesses in order to suggest improvements, only the weaknesses are discussed here.

4.1 Potential improvements of ISO 11064. Several potential improvements of ISO 11064 are identified on the basis of the study. These suggestions should be interpreted in the context of the Norwegian petroleum industry. However, this does not disqualify them from being relevant to other industrial domains. Thus, they might be applicable to an international standard, but making the suggestions domain independent requires further investigations. The following parts correspond to those of part 3.2.1 through 3.2.7.

4.1.1 Scope of ISO 11064. The scope of a project should be decided as part of Phase A: Clarification (see figure 1) to allow for the practical use of the standard in remote control of platforms and IO. We suggest the definition of CC to be the "combination of control rooms, control suites and control stations which are functionally related, independent of physical location".

The principles of ISO 11064 are to be followed for the design of a driller's cabin. Drilling is a complicated operation, but the production of oil and gas is even more demanding. For these kinds of projects, the activities required in ISO 11064 can become too extensive. Making it simpler to adapt the use of the standard to each project might reduce these problems, based on a minimum requirement set (MRS). Another option is to include an additional part that is appropriate for smaller control units, but this may be outside of the standard's scope and will not be further discussed here. It should be noted that the use of ISO 11064 for smaller units might not be ideal and that other standards or governing documents might be more suitable, such as CRIOP.

The design process proposed in ISO 11064 is not as suitable for modification projects as it is for design of new systems. A modification of a CC face many preset conditions, e.g. the location and size of the CC can not be changed without becoming too expensive, and so the design process must be adapted to these conditions. How this can be done, and to what extent, is not clear in the standard. This problem might be solved by a clarification of the possibilities of adapting the use of the standard to each specific project or establishing a MRS. Further investigations are required to suggest how this can be done.

Part one of ISO 11064 states a total of nine "*General considerations and principles of ergonomic design*" [2]. These principles should be stated clearer in the standard, since they cover important aspects of CC design. Some of these principles are directly related to the findings in the study and are discussed in the appropriate sections below.

It should be explored if the standard could accommodate the new control rooms used in IO, e.g. collaboration rooms and operation rooms used onshore and offshore to perform or support part of the control room activities.

4.1.2 Organizational issues within the CC. The responsibilities in CC and between CC at the plant and onshore support using IO and virtual organizations may become unclear if they are not properly defined. This is especially important in an emergency situation. ISO 11064 does not cover this sufficiently, but changes in the standard could be amended into step 5: design job and work organization, in figure 1. More research is required on this area.

4.1.3 Organizational issues in the project. Some see HF tasks as separated from other project activities, i.e. being 'out of sync' with the rest of the project. Principle two in part one of ISO 11064 states: "Integrate ergonomics in engineering practice" [2]. To make this simpler, a less rigid and more goal-based approach to the design process might be a solution. This is further discussed in part 4.3. Another option is to require some kind of agreement or consensus between HF personnel and project management before decisions can be taken. However, letting HF 'take control' of the project progress is undesired, since HF personnel have limited economic responsibilities for the overall project. A third option is to use a cost/benefit approach to decide which HF activities to performed, when, and to which level of detail. This can be achieved by expert estimates, but the extent of an analysis must always take into account the maturity of the design, the information available etc.

HF activities should aim at satisfying engineering needs. Then the processes in ISO 11064 will become better synchronised with the project processes. I.e. instead of just doing a function analysis and allocate functions to human and/or machine, it's more appropriate assist engineers in understanding the way operators actually operate the system. Still, HF personnel must identify all major HF issues before design freeze to avoid potentially hazardous design solutions.

The application of the standard must be adapted to each project. This seems to be especially hard for modification and smaller units as mentioned above, but a common challenge seems to be that people find the standard too vague. However, an international standard can not be too concrete, as it shall cover CC design in many industrial domains. A more goal-based approach might solve this without making the standard too specific. This is further discussed in part 4.3.

The fact that operators can be unavailable early in a project raises serious challenges of the user participation. Principle seven in part one of ISO 11064 is "*Ensure user participation*" [2]. This becomes a problem when there are no users available. Some use personnel with long operative experience (e.g. one person) early in the project and include them as the users in the design process. This might not be ideal, but it's better than having no users at all. Another solution is to use operators from similar systems. The latter approach is commonly used in the Norwegian petroleum sector.

4.1.4 Competence requirements. Principle one of ergonomic design in part 1 of ISO 11064 states: "*Application of a human-centred design approach"* and principle two states: "*Integrate ergonomics in engineering practice*" [2]. Having an appropriate person taking care of the HF aspects is a critical success factor and ISO 11064 has established that HF competence must be incorporated into a project. Both Oil & Gas operators and engineering companies often hire external HF consultants to implement the principles of ISO 11064 (and other standards/regulations) into the design. ISO 11064 should, in addition to establishing HF competence, include requirements that HF personnel have at least a basic knowledge of the type of system the CC is designed for, or to obtain this knowledge before starting the work. Otherwise, important aspects can be missed and poor communication between the HF personnel and the rest of the design team might occur. Further research is required to suggest specific requirements.

It does not seem to be necessary to establish specific competence requirements to the interdisciplinary design team. However, the need for project management knowledge and competence should not be underestimated, and should be explored or discussed in the standard.

Principle eight in part one of ISO 11064 states that "*experienced and future users shall form part of the design team*" [2]. This seems to be sufficient requirements for users' experience.

4.1.5 Work organization and procedures. ISO 11064 requires that ergonomic principles are taken into account when work systems are designed [2]. A normative reference for these principles is ISO 6385 - Ergonomic principles of the design of work systems, which considers itself to be "*the core ergonomic standard from which many others on specific issues are derived*" [1]. ISO 11064 needs to take remote support/monitoring/control and IO issues into account in the design of work systems. References to ISO 6385 are too vague and insufficient for the way ISO 11064 is constructed. It's also important to notice that equipment like for example the SAS is not designed from scratch for each platform design, but is rather a standard product that is amended to fit the specific needs of the project in which it shall be part. Hence, there are strong practical limitations on e.g. the allocation of functionality between humans and machines as soon as a SAS system is ordered.

ISO 13407 is concerned with the human-centred approach and is referred to for further details in ISO 6358 [1] and it's a normative reference in part seven of ISO 11064 [5]. Chapter 7.2 in ISO 13407 specifies the user and organizational requirements and give good guidance on the relevant aspects to be considered.

4.1.6 Documentation. Large pieces of documentation, e.g. thick reports, can make it hard to separate important issues from less important ones and can also make it harder to understand what the results imply and how they can be implemented. Principle nine of ergonomic design in part 1 of ISO 11064 states; "*Document ergonomic design basis*" [2]. This is to ensure that the documentation is present, but it will not necessarily be clear and manageable. The actions and the conditions for the design and use of the CC are the most important to document. According to the findings in the study, documentation can be unclear and hard to manage. One solution to this problem can be to develop templates for reporting the ergonomic design basis, e.g. as an informative annex to part 1 of ISO 11064. For example, there are HF-consultants who successfully use mind mapping software as a tool to graphically present the results from their HF work. There can be many ways to achieve more concrete results, but the discussion of this is too extensive for this paper.

4.1.7 Experiences from similar CCs. This study shows that experiences from similar CCs are applied successfully in current practice, but being a vital point, this should be emphasized in the standard. This aspect could be included in the process diagram shown in figure 1 to clearly state that this is an important activity, and not only be in the text as is the case today.

4.2 Potential improvements of CRIOP. CRIOP is a tool that needs adaptation to a project before it's used. There were no serious problems reported regarding the adaptation, but additional guidance was requested by several interviewees.

Adapting the CRIOP checklists to a project can be time consuming. Identification of relevant commonalities present in similar projects can be used to develop templates to make this adaptation more effective. Templates can be made for new CC design for an offshore installation, modification of the same, design of a new driller's cabin on a mobile unit, modification of the same etc.

Scenario templates can also be developed. Scenarios can be used in the design phase [13] and is reported to give valuable feedback on the design. Caution should be taken if scenarios from the design are reused in V&V, as this is a poor validation of the design. Scenarios in CRIOP have been used to explore safety and security of new solutions – and as such it is a very useful tool. The use of Scenario analyses becomes much more important when implementing IO and some form of virtual organization. The scenario analysis is an important tool to test new procedures and organizational responsibilities in a distributed organization (or virtual organization) which is common in IO. It seems that the scenario analysis could improve safety and security in IO better than learning from accidents after implementation. Scenarios can be shared across an industry sector to form a 'best practice'. The use of templates can reduce the cost of a CRIOP and improve the quality and give increased cost/benefit. CRIOP should also be adjusted to IO and the use of collaboration rooms, and this is a planned development of CRIOP in 2008.

4.3 Goal-based approach. Adapting to a goal-based approach will make ISO 11064 more capable of coping with technological changes and make it more flexible in terms of application to various industrial domains. A prescriptive standard constitutes specific means to achieve compliance with the standard. E.g. "*you shall install a 1 meter high rail at the edge of the cliff*" [14]. A prescriptive approach dictates the what's and the how's of the product that has been made or the process that was used to develop and test that product [15]. A goal-based standard does not require as specific means to achieve compliance, e.g. "*People shall be prevented from falling over the edge of the cliff*" [14]. Goal-based standards rather set the goals and leave the question of how to achieve these goals more open. This allows for many alternative ways to achieve the same goal.

ISO 11064 describes the design process (phases and activities to perform) and it specifies a number of more or less specific requirements. The focus on the design process rather than the product means that it has a somewhat goal-based approach. However, the rather detailed requirements of which analyses one shall perform, a design process made for designs that are made from scratch and the size of it (six published parts and one part still in draft) suggests that it could be made simpler and more flexible than it is today. A stronger orientation against goal-based regulation is one way to achieve this.

One advantage of a more goal-based approach is the increased capability to handle changes in technology. It takes years to develop an international standard, and once it is published, it should last for many years before a (major) revision is required. Thus, it is important that a standard can withstand changes in the real world without becoming outdated, e.g. because of the introduction of new technology and new ways of working.

The essence of a top-down approach to design is incorporated into ISO 11064 [16]. However, many systems are not designed top-down, so other design strategies (e.g. bottom-up, evolutionary, component-based) might be just as applicable for a project. Software has become a major part of the systems on an advanced offshore installation. A more goal-based approach can improve the standard's capability to handle reuse (e.g. for SAS) and the use of COTS (Commercial Off The Shelf) software. Reuse can improve software productivity and quality [17]. Designing with reuse in mind is important for long-term cost/benefits, but can have serious safety implications if not done with care [18]. Regardless of the difficulties, there is a growing interest in acquiring COTS products in a safety-critical context [19].

The increased freedom of a more goal-based approach is important, but this places more responsibility on the responsible parties, i.e. the operator companies, engineering companies etc. Goal-based regulations also require a closer cooperation between operator and regulator. Adapting to a more goal-based approach may allow for the design of systems that better allow for deviations from their predefined operational boundaries. Resilience is the ability of systems to anticipate and adapt to the potential for surprise and failure [20]. A possible regulatory future is the move towards judging resilience, i.e. rather to know exactly which problems an inspection object is having, the inspector might want to judge its resilience. What to base this judgement on is only beginning to be examined [21].

4.4 Use of Safety Case. A safety case can be used when implementing a more goal-based approach. There are several definitions of a safety case. The goal-based standard DEF-STAN 00-56 Issue 3 states that "*A Safety Case is a structured argument, supported by a body of evidence, that provides a compelling, comprehensible and valid case that a system is safe for a given application in a given environment*" [22]. A detailed description of all aspects of the safety case is far too extensive for this paper, and the reader can consult UK HSE legislation [23] for this. In short, a safety case can be used as a tool to convince authorities (and others) that a system is acceptably safe to use within a given context. Figure 4 illustrates the general relationship between standards and safety cases.

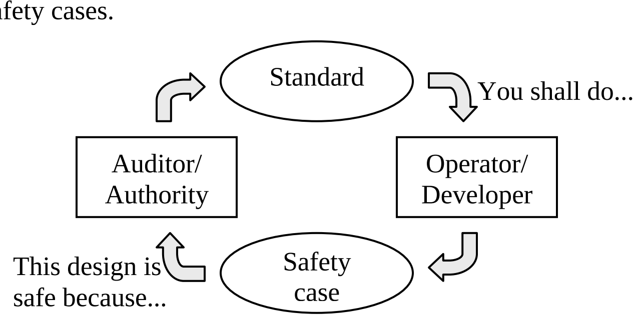

Figure 4. The relationship between standards and safety cases.

It is not sufficient to just achieve an appropriate safety level. Developers and operators of safety-critical systems are also required to demonstrate that the system actually is, and will continue to be, safe enough. One way to demonstrate this is to use a safety case. A safety case is basically an argument (supported by evidence) that a system is acceptably safe (a claim) to operate in a given context. It can be difficult to formulate reasonable arguments or produce convincing evidence. This can be due to limited safety expertise, lack of integration with design or lack of supporting evidence and will require a significant "culture change" to overcome [14].

4.5. Threats to validity. The validity of this study faces some threats, which are briefly discussed here.

4.5.1 Construct validity. This study was constructed to be exploratory and the main objective was to map experiences from using ISO 11064. An interview guide was prepared and used for all interviews, but with some modifications depending on the type of actor being interviewed. The interview guide was inspected by a walkthrough before the interviews started.

4.5.2 Internal validity. Misunderstanding the interviewees' answers is the most obvious threat to internal validity. The use of open-ended questions allowed the interviewees to focus on the issues they felt were most important.

A second threat is that people are reluctant to tell anyone about their mistakes and unsuccessful projects. However, anonymity was guaranteed and the interviewees seemed more than willing to talk about mistakes done in the past.

The participants were selected from major companies involved in the Norwegian petroleum industry by convenience sampling. Snowballing was also used, i.e. that the interviewees were asked to propose other potential interview candidates at the end of each interview.

4.5.3 External validity. The first threat to the external validity is that this study only includes the Norwegian petroleum industry. However, we claim no generalization outside of this sector.

The participants represent different types of actors in the industry. No participants were however included from the sub contractors, e.g. suppliers of SASs.

The results are based solely on qualitative data and on one research method only. However, this is sufficient for the exploratory purpose of this study.

5. Conclusions and future work

ISO 11064 gives positive contributions to the design of CCs. The level of experienced usefulness reported by the interviewees depends on the context (e.g. project type, complexity) in which they have used the standard, which parts of the standard they have used etc.

Part 1 of ISO 11064 gives good process guidance. This part is the most widely used and was also pointed out as the most important part of ISO 11064 by the majority of the interviewees. Part 3 and part 7 were also said to be important.

The application of ISO 11064 must be pragmatically adapted to each project. All aspects of HF must be considered in the design process, but all activities described in the standard are not necessarily required to achieve compliance with the standard. Improved guidance on how to adapt the application of ISO 11064 is needed.

Success seems to depend on individuals rather than the use of a specific standard. Hence, establishing appropriate competence requirements is important, and will become even more important with the introduction of IO.

This study has revealed several areas where ISO 11064 can be improved. However, the findings are concentrated on part 1 of the standard. The next step will be to conduct a survey to further examine the issues described in this paper.

ISO 11064 needs a stronger orientation towards goal-based regulation to cope with current and future technology changes. The introduction of IO sets different requirements to a CC and raises other safety issues than the traditional plant with an on-site CC, see part 4.3.

6. Acknowledgements

We wish to thank the Norwegian forum Human Factors in Control (www.hfc.sintef.no) for its funding of this study and we thank all the participants for their contributions.

7. References

1. ISO 6385: *"Ergonomic principles in the design work systems"*, International Organization for Standardization (2004) p. 1-11.
2. ISO 11064-1: *"Ergonomic design of control centres - Part 1: Principles for the design of control centres"*, International Organization for Standardization (2000) p. 1-25.
3. Wood, J.: *"Control room design"*, in *Human factors for engineers*, C. Sandom and R.S. Harvey, Editors. (2004), Institution of Electrical Engineers: London. p. 203-233.
4. ISO 11064-3: *"Ergonomic design of control centres - Part 3: Control room layout"*, International Organization for Standardization (1999) p. 1-21.
5. ISO 11064-7: *"Ergonomic design of control centres - Part 7: Principles for the evaluation of control centres"*, International Organization for Standardization (2006) p. 1-9.
6. PSA: *"Guidelines to regulations relating to design and outfitting of facilities etc. in the petroleum activities (The facilities regulations)"*, Petroleum Safety Authority Norway (PSA), Norwegian Pollution Control Authority (SFT), Norwegian Social and Health Directorate (NSHD) (2002).
7. Sintef: *"The CRIOP Web"*. [Internet page] 2007 [cited 2007 11/07]; Available from: http://www.criop.sintef.no.
8. Johnsen, S.O., et al.: *"Identification and reduction of risks in remote operations of offshore Oil and Gas installations"*, paper presented at the *ESREL 2005*, Sopot, Gdansk, Gdynia, Poland, 2005.
9. Kirwan, B.: *"A guide to practical human reliability assessment"*, Taylor & Francis, London (1994) 592 s.
10. Yin, R.K.: *"Case study research : design and methods"*, 3rd ed, Applied social research methods series ; vol. 5, Sage, Thousand Oaks, Calif. (2003) XVI, 181 s.
11. NORSOK S-002: *"Working environment"*, The Norwegian Oil Industry Association (OLF) and Federation of Norwegian Manufacturing Industries (TBL), Standards Norway: Lysaker, Norway (2004) p. 1-56.
12. Oljeindustriens Landsforening (OLF - Norwegian Oil Industry Association) and Institutt for Energiteknikk (IFE - Institute for Energy Technology): *"The Future of the Norwegian Oil and Gas Industry"*. 2004 14.11 2004 [cited 2007 01.08]; Available from: http://www.olf.no/io/rapporterpresentasjoner/?23939.pdf.
13. Rosson, M.B. and Carroll, J.M.: *"Scenario-based design"*, in *The Human-computer interaction handbook*, A. Sears and J.A. Jacko, Editors. (2003), Lawrence Erlbaum: Mahwah, N.J. p. 1032-1050.
14. Penny, J., et al.: *"The Practicalities of Goal-Based Safety Regulation"*, paper presented at the *Aspects of Safety Management: Proceedings of the Ninth Safety-Critical Systems Symposium*, Bristol, UK, 6-8 February 2001: Springer. p. 35-48.
15. Fenton, N.E. and Neil, M.: *"A strategy for improving safety related software engineering standards"*, *IEEE Transactions on Software Engineering*, (1998) **24**(11): p. 1002-1013.
16. Wood, J.: *"Control room design"*, in *People in control : human factors in control room design*, J. Noyes and M. Bransby, Editors. (2001), Institution of Electrical Engineers: London. p. 189-206.
17. Lee, N.-Y. and Litecky, C.R.: *"An Empirical Study of Software Reuse with Special Attention to Ada"*, *IEEE Transactions on Software Engineering*, (1997) **23**(9): p. 537-549.
18. Bowen, J.: *"The ethics of safety-critical systems"*, *Communications of the ACM*, (2000) **43**(4): p. 91-97.
19. Ye, F., et al.: *"COTS product selection for safety-critical systems"*, *Lecture notes in computer science*, (2004) **2959**: p. 53-62.
20. Woods, D.D. and Hollnagel, E.: *"Resilience engineering: concepts and precepts"*, ed. E. Hollnagel, D.D. Woods, and N. Leveson, Ashgate, Aldershot (2006) XII, 397 s.
21. Dekker, S. and Hollnagel, E.: *"Resilience Engineering: New directions for measuring and maintaining safety in complex systems"*, School of Aviation, Lund University: Lund, Sweden (2006) p. 10.
22. DEF STAN 00-56: *"Ministry of Defence Interim Defence Standard 00-56 Issue 3"*, in *Safety Management Requirements for Defence Systems*, UK Ministry of Defence, Defence Standard (2004) p. 1-15.
23. SI 2005/3117: *"The Offshore Installations (Safety Case) Regulations 2005"*, Queen's Printer of Acts of Parliament: UK (2005) p. 1-34.