A Study of a Technological Development Process

Human factors - the forgotten factors?

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Abstract

The aim of this study was to explore how human factors were taken into account in the development of a new type of drilling equipment. This study is part of a larger project on the understanding of human factors in the design and implementation of automated drilling technology. The principal study was a longitudinal study lasting 4 years that involved 43 interviews, offshore and onshore observations, and 2 surveys.

Method

The analysis in this paper is based on 7 informants who were either part of the design team or the paramount project team developing new automated drilling technology for an offshore oil- and gas-producing installation in the same development project, in addition to project documents. The informants were interviewed using semi-structured interviews, and grounded theory based on the coding process of Corbin and Strauss (1990) was used to analyse the data.

Results

The core category was found to be insufficient human factor analyses performed in the development phase due to the two main categories, namely 1) insufficient information coordination and 2) narrow focus in different phases of the project. This was found to contribute to increased costs, low user friendliness, and end users' insufficient knowledge of safe usage and potential risks.

Conclusion

Our conclusion was that homogenous top competence involving technical aspects contributed to developers' lack of understanding of the need for sufficient analyses of end user requirements and of the tasks that would be affected by the new technology. Hence, we argue that technological development could benefit from including human factors experts from the project's outset to bridge the gap between the lack of relevant information and sufficient information on which to base development decisions. In addition, we contend that performing human factors analyses throughout the development of a project would be beneficial due to the potential of hindering cultural aspects such as a non-questioning culture, which is viewed as a hazard in high-risk organizations.

Keywords: human factors, human reliability, automated technology, safety, petroleum industry, technology development

1.0 Introduction

The offshore oil and gas industry is considered a high-risk industry where minor incidents can lead to major accidents; thus, safety is a main priority (Årstad et al., 2010). Consequences of non-successful development and implementation of new technology have the potential of resulting in unwanted incidents and, in worst-case scenarios, major accidents. Because studies from the nuclear industry show that between 20 and 50% of incidents involve design mistakes (Taylor, 2007), it is important to involve strategies that ensure safety in technological development projects. Traditionally, the focus on safety in the development of new technology has been on technical aspects. Although lately there has been a growing focus on the human end users of the technology (ISO 11064, 2000; NORSOK, 2004; Petroleum Safety Authority [PSA], 2011), significant variations still exist in the actual use of human-centred design standards when developing new technology (Aas & Skramstad, 2010).

Sætren and Laumann (2015a) conducted a study where they found that too much trust contributed to a non-questioning culture on an offshore oil and gas installation and that this non-questioning behaviour resulted in technology acceptance. Moreover, the non-questioning culture was found to be a potential safety hazard because the end users insufficiently questioned the change process, and this was, at least to some extent, the cause of a serious unwanted incident on the platform. Hence, we found it interesting to investigate further some of the aspects of the trust the end users mentioned during the implementation phase and after the technology was in use. In their article, Sætren and Laumann (2015a) pointed out that one of the reasons the crew trusted the new technology to such a degree was that they had a general trust in the management. Furthermore, prior to the actual implementation, the crew members emphasized that they were properly trained and informed about the technological change to come because those who developed the technology understood the level of competence the crew held and their everyday work. In this paper, we therefore want to explore to what degree those who developed the technology knew the end users for whom they were developing the technology. Thus, we explored the process of developing technology, which automated parts that were previously handled manually by end users. Particulars about the technology and work routines are confidential because they could potentially reveal informants' identities and hence are not described in detail.

The purpose of the study was to investigate the safety aspects of the work processes and the outcome of the development process. The specific research question based on this purpose is: *How is safety through human factors and human reliability analyses ensured during a development process of automated technology in a high-risk industry?*

1.1 Safety in Complex High-Risk Systems

Several theoretical perspectives assess safety in high-risk systems. Reason (1990) distinguishes between *active* and *latent failure*, where active failures are errors where the consequences are immediately visible. They typically occur due to operator error, and there often is a clear relationship between cause and effect. Latent failures, on the other hand, refer to decisions and actions taken by those removed from the direct control interface but who still affect the outcome. These decisions and actions could be taken long before the occurrence of an unwanted incident and thus are unknown latent conditions. This concept is illustrated by Reason's (1990; 1997) Swiss cheese model, where latent conditions in combination with active failures could lead to a breach in the defence in depth and result in an accident.

Furthermore, active failures tend to refer to what Reason (1990) calls human error. *Human error* describes situations where human mental or physical actions do not lead to the planned outcome, and this theory investigates which human errors exist and why humans err. It is based mainly on human cognition, that is, how people store, select, and recall knowledge. Errors are categorized as intended and unintended. Slips and lapses are related to unintended actions and connected to how actions are performed as well as the attention given to the task.

Mistakes are related to intended actions and connected to how problems are solved. Additionally, Reason (1990) mentions violations, which he refers to as deliberate deviation from procedure that is not necessarily reprehensible if they do not involve an intention to damage the system. Such unintentional actions could still lead to major accidents, as noted by Rasmussen (1997). His theory shows how everyday normal behaviour could become disastrous because actions could lead to a migration towards the boundaries of acceptable safety practice. Thus, the interaction of the effects of decisions made by actors in their normal work context must be considered. Decisions are not made in isolation but in a complex social context where interactions and interrelationships can produce outcomes that might be difficult to predict. In this way, failure can be a result of normal behaviour influenced by, for instance, the competing goals of safety and production (Rasmussen, 1997).

Another theory that assesses safety in high-risk organizations is high reliability organizations (HRO) by Weick and Sutcliffe (2015). This theory is related to organizations that operate in high-risk environments but experience considerably fewer accidents than expected compared to the degree of risk in which they are operating. The authors argue that continuous mindful organizational practices can prevent major accidents and promote safety. The five distinct practices are 1) preoccupation with failure, 2) reluctance to simplify, 3) sensitivity to operations, 4) commitment to resilience, and 5) deference to expertize. These five mindful techniques form a collective cognitive infrastructure within a system, which enables the system to manage the unexpected and prevent disastrous occurrences (Weick & Sutcliffe, 2015).

1.2 Human Factors and Human Reliability in Technology Development

Methods to expand the understanding of the integration between human and machine are becoming increasingly important. During the last decades, the number and complexity of large and complex technical installations, such as those for petroleum, aviation, and nuclear industries, have increased (e.g. Stamnes, Zhou, Kaasa, & Aamo, 2008; Strøm, 2008; Wilpert, 2005; Wolfe, Morris, & Baule, 2009). With the growth of complex installations, the possibility of dangerous consequences for humans and the environment also are increasing. Results from analyses of major accidents and research of on system safety engineering show that human actions most likely play a role in triggering these accidents (e.g., Albrechsten & Weltzien, 2013; Baker et al., 2007; Demichela, Pirani & Leva, 2014; Taylor, 2013. For instance, reports regarding some of the most serious blowout accidents in petroleum such as Piper Alpha, and Macondo, have shown that triggering causes include the little understood interaction of factors in various system levels, such as technical, human, social, organizational, managerial, and environmental (Cullen, 1993; Graham et al., 2011; Paté-Cornell, 1993; Rasmussen, 1997; Reason, 1990, 1997; Turner, 1978; Wilpert, 2005). Consequently, it is important to minimize such aspects by, for instance, searching for adequate design solutions under conditions of distributed decision making where different competencies and disciplinary approaches are brought together in settings of cooperative work (Rasmussen, 1991). This could be done by involving human factors specialists to minimize a mismatch of the developer's and the user's conceptual model of the technology to be used (Salvendy, 2006; Stanton, Salmon, Walker, Baber, & Jenkins, 2013; Wickens, Lee, Liu, & Becker, 2004).

One view of human factors is that they are concerned with the design of novel systems in areas such as usability and safety. Human reliability, on the other hand, focuses more on verifying the safe performance of human actions in interactions with the system (Boring, 2007). However, this segregation of the two fields may not be accurate: the lines between them are blurred, as human reliability often is integrated into human factors (Boring & Bye, 2009; Boring et al., 2009; Gordon, 1996); human reliability analyses usually include task analysis, human error identification, and suggestions for human error reduction (Kirwan & Ainsworth, 1992; Shorrock & Kirwan, 2002).

1.3 Human Factors Challenges in Offshore Drilling

In drilling and well operations, operational tasks are becoming increasingly complex and thus have a high risk potential (PSA, 2004; van de Merwe, Øie, & Gould, 2012). In addition, operations in mature reservoirs are increasing, which makes operations more demanding (PSA, 2004). Technological development therefore is inherently complex because it must consider drilling in mature fields, allow drilling for oil in previously undrillable targets, and pay attention to the end users for safe operations. It is not sufficient to consider only the technological solutions, as the human and organizational factors also are important in technological development projects in the offshore context. Qualitative human factors analyses has been used, but mainly in relation to engineering design and verification of control systems and control rooms (Aas & Skramstad, 2010; Gould, Ringstad, & van de Merwe, 2012).

Human factors challenges exist in drilling and well operations. These include lack of active management, training and competence; fluctuations in activity level; insufficient communication (Jærnes et al., 2005); task complexity (Jærnes et al., 2005; Rasmussen, Standal, & Laumann, 2015); and interorganizational cooperation (Jærnes et al, 2005; Milch & Laumann, 2016). To manage such challenges, a holistic approach seems important. This involves, for example, consulting end users and human factors specialists during the modification and installation of technological equipment (Jærnes et al., 2005; PSA, 2011). A lack of connection between technology and psychology has the potential to result in human error (Reason, 1990) because flawed comprehension of how to use the technology is likely to end in user error (Sheridan, 2008). Thus, it is recommended to adhere to several principles regarding human performance when developing technology in the oil and gas sector

(McLeod, 2015; PSA, 2011). Examples of such principles are allowing for human variability, providing information in a way that is compatible with how the human brain represents and thinks about the world, and ensuring that the status of equipment is visible where and when a user is likely to interact with it (McLeod, 2015; Norman, 2013). The Petroleum Safety Authority regards human and organizational factors as so important that it has declared that attention must be paid to them. Furthermore, the International Association of Oil and Gas Producers mentions that training and human factors, which form one of four areas under the category of prevention and improving well safety, are to be prioritized after the Macondo accident (OGP, 2013). Hence, interactions of human and organization must be optimized with the technical solutions (PSA, 2011).

1.4 Human Factors Methods

Using human factors analyses, such as function, task, and job analyses, is a way to make equipment user friendly by providing for human reliability (Jernæs et al., 2005; McLeod, 2015; NORSOK, 2004; PSA, 2011). Human factors research is a scientific field that consists of a combination of disciplines, including engineering, psychology, and computer science (Salvendy, 2006). The objectives of human factors analyses are to maximize human and system efficiency (Czaia & Nair, 2006), health (Zimolong & Elke, 2006), safety, (Palanque, Koorneef, Johnson, Szwillus, & Wright, 2004), team effectiveness (Salas, Wilson, Priest, & Guthrie, 2006) and cost efficiency (Rouse & Boff, 2006). To be able to reach these goals, human factors analyses provides several methods of analyses, such as *user analysis* (Wickens et al., 2004), *task analysis* (Kirwan & Ainsworth, 1992), *interface analysis*, *human error identification analysis* (Stanton et al., 2013), *training analysis* (Salas et al., 2006), and *cognitive workload assessment* (Ham & Yoon, 2001; Longo, 2015).

A *user analysis* is a method where the end users of a product are analysed so the designers have the best possibility to design optimal products based on the end users

(Wickens et al., 2004). In a *task analysis*, the tasks described include both the physical tasks and the cognitive tasks required in the analysed operation as well as any process that identifies and examines the tasks performed by the user who interacts with a given system (Kirwan & Ainsworth, 1992). *Interface analysis* methods are used to assess the human–machine interface of a particular system and are important to apply in both the design and operational stages of a product's lifecycle to ensure optimal interface design (Stanton et al., 2013). *Human error identification* is a method used to describe potential errors and consequences that might occur as well as recovery potential, probability, and criticality. Additionally, the method offers associated design remedies or human error reduction strategies (Shorrock & Kirwan, 2002; Stanton et al., 2013). *Training analysis* allows training designers to understand aspects such as what needs to be trained, who need to be trained, and where training is needed (Salas et al., 2006). *Cognitive workload assessment* consider the mental work necessary to complete a given task during a given period (Ham & Yoon, 2001; Longo, 2015).

1.5 Human-Centred Design Processes

Human-centred design emphasizes active and systematic participation by users and stakeholders in the process of designing new technology (Pascal, Thomas, & Romme, 2013). However, difficulties arise from the conflicts between technology-driven demands and the integration of human factors, such as the cognitive and action capacities, limitations, and needs of the human operator (Wilpert, 2005). One way of dealing with this is to use an integrated approach in the development of new technology. An integrated approach involves a human scientist, in this case a human factors specialist, as a full member of the design team from the beginning of the project, who, hence, has the opportunity to analyse requirements of the system (Jærnes et al., 2005). This could improve accident prevention, health, and comfort, and various ISO standards may be considered (e.g., ISO 11064, 2000; ISO 6385, 2004). For example, the ISO 11064-1 (2000) is part of an international standard developed for designing control centres based on human-centred design. The standard concerns optimal design processes and covers all types of control centres, including process industries, transportation and logistics, and people deployment services. As the ISO 11064-1 is rather general, it can be applicable for a broader spectrum of system design processes. The standard focuses on elements such as human-centred design, integrating ergonomics in engineering practice, user participation, error-tolerant design, feedback design, and task analysis in every step of the process. The ISO 11064-1 (2000) uses ISO 6385 (2004) as a normative reference, which establishes fundamental principles of ergonomics and human factors as basic guidelines for the design of work systems in general. One of the main purposes of the ISO 6385 is to involve human factors in the design to achieve a balance between the human, social, and technical requirements. The standard emphasizes that ergonomics should be integrated with other aspects of the design.

1.6 Change Management Theories

The development of new automated drilling technology brings change to the everyday work practices for the end users. In addition, a large-scale technological development project requires an optimal development and implementation process as well as change management. Most change management theories consist of a recipe for making a transition from the present situation to a future desired situation. For instance, Kotter (1996) outlines an eight-step program for implementing change, Kanter, Stein, and Jick (1992) offer 10 steps for executing change, and Luecke (2003) provides seven steps for a successful transformation. Elements such as creating a vision; supporting a strong leader; institutionalizing success through formal policies, systems, and structures; focusing on results; and institutionalizing the change are common to these change management theories. Further, a common factor seems to be that change management theories are leader centric and preoccupied mostly with making the change recipients willing to change, and resistance to change is often viewed as something that must be overcome (e.g., Armenakis & Harris, 2009; Cummings & Worley, 2015; Furst & Cable, 2008; Ghoshal, 2005; Kanter et al., 1992; Kotter, 1996; Sætren & Laumann, 2015b). However, whether theories promoting agreement and the prevention of resistance are optimal for changes in high-risk industries is questionable.

In the sections that follow, we explain the qualitative approach utilized for this study as well as the results. Further, we provide a general discussion prior to the presentation of our conclusions.

2.0 Method

We selected a qualitative approach for this study because we wanted deeper insight into the processes of developing new technology, specifically regarding the understanding of the end users by those developing the technology. Moreover, we did not identify predefined categories prior to the study. Grounded theory is designed to find categories and concepts, and this method helps researchers explore the connections between the categories and concepts in the process of building a theory. Grounded theory is a method of analysis where the aim is to build a theory grounded on the data collected, hence the name (Strauss & Corbin, 1990).

The results of the current study are based on seven semi-structured individual interviews with seven informants in addition to project documents. This study is part of a larger project on the understanding of human factors in designing and implementing automated drilling technology. In the larger project, 43 interviews were conducted over a period of 4 years, and offshore and onshore participatory observations and two surveys were completed in the larger project. The seven interviews for this study were the last part of the longitudinal study, and were thus the last to be conducted.

2.1 Participants

For this study, 7 informants were chosen because of their relevance. The informants were part of a project that developed new automatic drilling technology for the offshore petroleum industry. In this development project, the informants were part of the project team or the engineer developer team. Further, the informants represented three companies that cooperated, among others, on this specific development, namely the customer, the main contractor, and the main subcontractor (see Figure 1). The informants were selected based on their involvement in the development process of the technology, and more than one person was chosen from each of the three companies. Because the development of the technology occurred some time before the interviews were conducted, the informants were further chosen based on their current work, which was either a continuance of this project or similar projects. The interaction complexity and its implications are described in greater depth in the context section in the results.

INSERT FIGURE 1 ABOUT HERE

2.2 Interviews

The seven interviews were conducted over two months and were based on either telephone or video conferences, according to the preferences of the informants. They lasted approximately one hour each. All interviews were conducted individually with only the informant and interviewers present. The interviews were recorded and transcribed.

In this project, the interview guides were semi-structured (Kvale, 1996), which implies that they contained open-ended questions that allowed the informants to talk freely about different aspects of how they worked within the project. The interviews were divided into different topics, including general questions concerning work processes, safety concerns during the process, and the perceptions of end users. Examples of questions were: How did you consider safety when you were developing the new technology? Which analyses were performed in relation to safety? Did ISO standards apply for these types of projects? How well did you feel you understood the workday of a driller? What worked well in the development process, and what would you like to have changed?

2.3 Analysis

Grounded theory was used to analyse the data. Grounded theory is an inductive qualitative method of analysis that consists of open, axial, and selective coding. Open coding refers to breaking down the raw data to compare and conceptualize the data into categories. Axial coding is the process of categorizing the data broken down during open coding and making connections between the categories. Selective coding, the final step, involves comparing the categories and selecting the central phenomenon, referred to as the core category (Strauss & Corbin, 1990). By using the guidelines of Strauss and Corbin (1990), the underlying philosophy of science is post-positivistic and the ontology is objectivistic. By this is meant that one indicates an objective reality that is ready to be discovered, explored, and understood. It further implies that there is a stable underlying structure waiting to be revealed for the scientist examining it and an ontological point of view where the existence of an objective reality is prominent. Because grounded theory is not a linear process, data collection and analysis took place simultaneously.

2.3.1 The coding process. The process of coding the data using the principles of Strauss and Corbin (1990) commenced with the open coding of the first interviews. This means that conceptual labels were placed on small parts of the interview to break down the data for examination and comparison. Consequently, these labels were placed on smaller parts, sometimes nothing more than a sentence per label. The next step was axial coding, which involves grouping the labels in categories. In other words, data were first broken down to smaller parts and then gathered into categories at a higher level of abstraction. This process was not linear, and results from open and axial coding were beneficial for interviews to come. When all interviews were completed and coded, the last step, selective coding, took place. Selective coding is not much different to axial coding, apart from occupying a higher abstraction level of analysis. This process involves finding the core category into which the central phenomenon of the categories is integrated. Another important aspect of grounded theory is saturation. In this study, saturation is questionable due to the number of interviews conducted. Nevertheless, based on the seven interviews, we argue that we have satisfactory saturation, as we did not receive additional or new relevant information as the interview process continued. During the entire process, memos were written to record initial and mature ideas regarding the formulation of theory (Strauss & Corbin, 1990).

3.0 Results

In this section, the context will be presented before the results are presented as categories. Further, the categories are visualized as a model (see Figure 2).

3.1 Context

To provide insight into the situational factors within the current study, information about the context of the informants is presented. The context includes two categories: the technology and the organizational and work environments of the project group and the engineer development team.

3.1.1 The technology. This particular technology was a modification of earlier manually driven technology, which was automated and developed to reach previously undrillable areas. Because this was to be used in mature areas, it also meant that it would be used in more risky operations. In addition, since this was a new way of drilling, it meant a shift in cognition, routines, and procedures for the operators and crewmembers in comparison to using conventional drilling techniques.

3.1.2 The organizational and work environments for the project group and the engineer development team. We interviewed people from two teams, namely the principal project group and the engineer development team, who both were represented by several companies cooperating in the development process (see Figure 1). The project group originally consisted of representatives from the customer (the operator company), the main contractor, the main subcontractor, the company that employed the drilling crew on the offshore installation for the implementation, and a consultancy company. The project group had the principal responsibility for the rather complex project and changed some of the members during the development and implementation process based on whom they considered necessary members of the group. The engineer development team was the team developing a model for planning drilling operations based on real-time data and a model for the interface of the screen for the drillers. This team included representatives from the customer (the operator company), main contractor, and main subcontractor. The members of the engineer development team frequently met during the development phase of this new product, and during these meetings, they discussed the development of the design, presented progress reports, and performed risk analyses. In addition, other subcontractors were responsible for different components of the technology; however, we focused only on this main subcontractor. The project group made the principal decisions and worked closely with the engineer development team. When either of the teams felt it necessary, experts in different areas were brought in to contribute to, for example, HAZOP ([hazard and operability study]; Stanton et al., 2013), HAZID ([hazard identification study]; McCoy et al., 1999), FMECA ([failure mode effects and criticality analysis]; Stanton et al., 2013), and peer reviews for risk analyses. The only human factors issues that were analysed were pertained to physical hindrances such as noise, lighting, walkways, and training staff on new restrictions due to new equipment in the area where they would usually work. No analyses, neither human factors nor human reliability analyses, were conducted that were directly associated with operating the new technology.

Apart from these meetings, the engineers in the engineer development team worked independently. More than one person from each of the three companies was part of this team; thus, the engineers held internal meetings within each company. However, these team members did not always work in the same location, despite working for the same company. Therefore, some of the engineers were not in the same area as others working on the same project daily, which contributed to interaction complexity, and they had to either travel by plane for meetings or conduct meetings via video conference. In addition, the main subcontractor extensively cooperated with a company located on another continent on the model they delivered on this project. Thus, informants stated that geographical distance and time difference could occasionally be an obstacle to optimal cooperation due to interaction complexity. Moreover, several of the engineer designers did not work solely on this project but also had other tasks to work on in their everyday work. As one informant sated, “I did work on other projects as well, so it could be a challenge to keep up the continuity on this project”. Consequently, work task complexity could make it occasionally challenging to remain diligent and focused.

3.2 The Categories Identified in the Study

The core category identified in this study was *Insufficient Human Factor Analyses Were Performed.* Additionally, two main categories were found: *Insufficient Information Coordination* and *Narrow Focus in Different Phases of the Project*. The results further include three outcome categories: *Extensive Costs*, *Low User Friendliness,* and *Insufficient Knowledge on Safe Usage and Potential Risk of the Technology by End Users*. Figure 2 shows the categories and how they are linked.

The model represents the results of the grounded theory analysis. The subcategories appear in the bottom line, which represents the most concrete level of the data denoted in the categories. The next level in the model is an abstraction of categorization represented by the two main categories. The highest level of abstraction in the model is the core category. At the top level, three outcome variables of the process on a more concrete level are presented.

INSERT FIGURE 2 ABOUT HERE

INSERT TABLE 1 ABOUT HERE

Next, the categories will be explained with quotes. First, our two main categories are presented with the subcategories integrated in italics, followed by the presentation of the core category and outcome variables.

3.2.1 Insufficient information coordination. This category represents a gap in information that probably is needed for an optimal development process versus information that was received and given. In other words, we found the information coordination within and between the teams had shortcomings that might have affected the product. One participant commented, “There was no guidelines on that [user friendliness], apart from being commercial and user friendly”. This indicates *insufficient requirement specification on user friendliness* regarding the order of the product from the customer to the main subcontractor. However, this did not seem to affect the perception of the information received and given in a negative way. For instance, the subcontractor was pleased with the information received from the customer regarding this development process because all the information that was asked for was received. As one informant stated, “We just talked to either [the customer company] or [the main contractor company] and, for the most part, we had easy access to information”.

According to informants, cooperation was good but not without reproach. Comments such as, “It was special. It was different, taking into consideration that we are not a company that primarily does product development, and this was quite a challenge” indicate that the main subcontractor was *inexperienced on commercial product development.* This inexperience seems to have negatively affected information coordination during the process of developing the automated technology.

Another aspect that influenced information coordination in an undesirable manner was a *lack of contextual understanding.* Informants were asked whether they wished they had known offshore work conditions before they began developing the products. The answer, “Yes, it would probably have been a considerable shorter way to reach the objectives”, indicates that they could not envision the offshore working conditions, which could have contributed to scarcity. Although cooperation was viewed as creditable, whether the inexperience regarding offshore working conditions resulted in insufficient information coordination was questionable. As one informant from the main subcontractor stated, "They [the customer company] did not know what information we needed, so we just made a list and they did their best to give us that information". It is therefore possible that developers did not ask for important information.

Another part of the subcategory *lack of contextual understanding* refers to an inability to understand who the end users were. When asked the questions, "How did you work according to the end user while developing the technology? Did you have in depth understanding of the drillers' work situation at that time?" one informant answered, "In the first phase, prior to actual drilling, we knew little of that". This indicates that the engineers developing the new technology knew little of the working conditions of the end users and of who the end users were prior to implementation and actual offshore testing of the product. Furthermore, in the project documents, the end users were designated mainly as the operators from the contractor company and partly the drillers. In addition, those who required knowledge about the technology, such as the tool pusher and the drilling supervisor from the operator company on the offshore installation, were mentioned. Informants further emphasized that all parties involved were included in the process from early stages, with one informant indicating, "In the design process, I think the involvement of all parties from the beginning was essential". However, the remaining drilling crewmembers were not viewed as end users of this technology according to the informants and project documents. The end users, as we interpreted them, could be divided into three different groups: the drillers, the drilling crew, and the operators from the main contractor company (Sætren & Laumann, 2015a), all of whom worked offshore in the drilling segment.

3.2.2. Narrow focus in different phases of the project. This category represents a gap between the optimal focus on human and technological issues in the development process. The focus was narrow in the sense that it was based mainly on technological safety. For example, statements such as, “I think the fact that we followed a pretty stringent design program and carried out checks along the way in terms of FMECAs and testing in terms of qualification testing was important” indicate that the technical factors were thoroughly reviewed by executing a broad range of tests to ensure technical reliability of the final product. However, statements such as, “I do not know which barriers were made to prevent human error” indicates that the end user was not considered to the same degree.

The aspect within the subcategory *lack of contextual understanding* is, in this regard, the insufficient understanding of who the end users were. This influenced a narrow focus on the human aspect of the development process. In reports regarding the technology, the operators of the main contractors and the drillers were viewed as end users of the technology. This was reflected in the training provided for the end users as well. The training provided for the regular offshore staff was a 3-day course for the drillers and tool pushers in a simulator that was similar to the real-life equipment but not completely authentic. The remaining crew had a 2-day introductory seminar with classroom training on how to rig the equipment. Both the 3-day course and the 2-day seminar were conducted several months before the actual drilling took place.

The subcategory *focus on technical safety* was interpreted as a shared understanding within both teams that the technical aspects were important and that members of both teams were highly competent regarding this. Nevertheless, an overly narrow focus on technical safety can lead to insufficient regard for human factors and human reliability.

For example,

Q: “Human error can occur. Do you take that into consideration when you develop a product?” A: “In a way I can say no, in the sense that we are focusing very much on the technical and doing things accurately”.

Similarly,

Q: “Did those composing the HAZOP have human factors skills?”

A: “If they had *what*?”

Nonetheless, to some degree, the focus indeed was on end users, and informants emphasized that end users were included in all phases of the development process. For instance, when an early technical safety workshop was completed, it included, among others, a driller and project members from the customer and the main contractor. The main subcontractor, however, was not included in this workshop. Informants emphasized that human factor aspects and access issues, such as noise, lighting, walkways, and training staff on new restrictions due to new equipment in the area where they would usually work, were included in the development process, yet these matters only pertained to physical hindrances. One informant stated, “… there were human issues like additional noise, additional lighting, walkways, access, education to people, perhaps not directly associated with the operation, but, you know, [when] there is new equipment in an area, there may be restrictions in that area”. Elements such as user analysis, task analysis, interface analysis, and human error identification analysis were not mentioned as a part of these considerations. Another aspect of user participation, according to informants, was that drillers and tool pushers were included in procedure making. As one informant said, “You could say that the procedures we use today have the stamp of the end users on them”.

The informants’ understanding of “*automation only leads to less human error*” was evident in several statements: “I think we designed this system so that there were enough safeguards within the system that the automation would compensate for the mistakes made by the operators” and “The technology is not idiot proof […] it can never be fully automated”. We interpreted this as having influenced developers’ narrow focus in different phases of the project in the sense that it diminished the human error aspect.

3.2.3 Core category: Insufficient human factor analyses were performed. The core category represents the project group’s and the engineer development team’s insufficient understanding of the need for human factor analyses during the design process. Based on the two main categories and the subcategories, we found that the principal phenomenon integrating the categories was an insufficient analysis process in the project.

3.2.4 Outcome variables. In the following subsections, the three outcome variables—extensive costs, low user friendliness, and insufficient knowledge on safe usage and potential risks of the technology by end users—are presented and discussed.

Extensive costs. Costs increase significantly for each phase in a development process. Thus, costs for changes made in the build phase or the operation phase are considerably higher compared to those for changes made during the analysis or design phase (Johnsen et al., 2008; McLeod, 2015; Rouse & Boff, 2006). In the current study, we found that changes to address errors and low user friendliness had to be made after the technology had been in operation. This probably resulted in significantly higher costs than if these elements had been discovered in earlier phases.

Low user friendliness. The informants did not consider the interface of the screen for the drillers user friendly, stating, for example, “In the new model [for the interface for the drillers] the user friendliness is very poor”. The engineers had not designed the screen’s interface intuitively from the drillers’ perspective. For instance, the users did not receive a warning signal if the input was not according to normal actions, and the model that the technology was based upon could not respond if users input data the wrong way. Furthermore, end users who did not comprehend advanced hydraulic models challenged designers. As one informant said, “Some of the challenges were that we who work with [developing] this know it well, but when you train other operators with lower education they have other premises on how to use it and understand what is correct use and what is wrong use of the technology”. Although the developers had worked to create the technology for such a long period, they stated that it was difficult for them to comprehend what kind of information the end users needed in the final product. They further stated that it was difficult for them to understand how the information should be presented to allow the end users to comprehend the correct usage of the technology. The engineer development team’s members stated that they did not fully understand other people’s situations compared to their own: “In a way we are in a bubble and can’t imagine how the world looks from others’ perspectives”. In addition, in replying to questions concerning in which stage they focused on user friendliness, one informant said, “If I were to do it again, we would have had a much higher focus on user friendliness earlier [in the process]”. In other words, it seems the project could have benefitted from a significantly greater focus on user friendliness in an earlier phase.

Insufficient knowledge on safe usage and potential risk of the technology by end users. The focus was mainly on the competence of the operators from the contractor company, who were viewed as “superior users”, according to documentation generated during the development process. Superior users from the contractor company were either highly educated engineers or especially talented staff members who were well trained in using this technology. The drillers did receive some training during the 3-day introduction course, yet we found this simulator training insufficient regarding the outcome of the process. Moreover, the remaining crewmembers also were affected directly by this technology and, hence, should have had sufficient training, as pointed out by one informant: “You need the whole crew in the mode of [the new technology], so in future projects we will include the crew in training and have training closer to the actual operation”. Furthermore, informants stated that errors made by drillers and the remaining crewmembers led to unwanted incidents when the new technology was in use: "… then the driller made a mistake […] but it was because he was not thinking in the mode of [the new technology]. He was thinking conventional". The incidents that occurred could potentially have led to losing the well. The reason they occurred was because the equipment was handled as if conventional drilling were in operation, which was the normal drilling operation for the drilling crew. If conventional drilling had been in operation, their actions would have been correct, but, with the new technology, operators had to significantly change their cognition and, occasionally, opposite actions were correct. This was also applicable for the remaining crew, as exemplified by one informant's statement: "Another example is a bloke from the crew who opened a valve that resulted in shutting down the system. We could have lost the well". Insufficient technical knowledge could be a safety hazard, and it has been found to be a leading cause of accidents (Department of Transportation, 1995).

4.0 Discussion

It is a rather well known fact that human performance plays an important role in managing the risk of major accidents in complex systems (Rasmussen, 1997; Reason, 1990). Thus, a poor design might have a disastrous outcome if end users do not comprehend the tasks they are expected to perform or the complexity of the technology (Lee, 2004). This is viewed as such an important aspect today that the Norwegian Petroleum Safety Authority (PSA) requires installations, systems, and equipment to be designed in a way that limits the possibility of human error (PSA, 2011).

In this study, we explored the process of developing technology that automates tasks end users previously handled manually. We posed the research question: *How is safety through human factors and human reliability ensured during a development process of automated technology in a high-risk industry?*

The findings, presented in Figure 2, indicate five subcategories, two main categories, and one core category in addition to three outcome categories. Insufficient requirement specification on user friendliness illustrates how *information coordination* could have benefitted from a focus on clarifying which information was needed in specific phases to obtain a more optimal result. The subcontractor could have asked, for instance, for additional specifications regarding user friendliness. Yet, due to inexperience on commercial product development and lack of contextual understanding regarding offshore working conditions, the developers might not have regarded this as important. What one does not know, one cannot possibly ask for. However, after the technology was implemented, other crew members made active errors that could have resulted in losing the well due to insufficient understanding of the new technology (Reason, 1990). This could be a result of the complexity of the project, where the design solutions did not adequately allow for different competencies amongst the end users (Gordon, 1996; Milch & Laumann, 2016; Rasmussen, 1991; Sneddon, Mearns, & Flin, 2013).

If the customer had considered what information the subcontractor needed and the main subcontractor had performed better when stating that there was more they needed to know, information coordination could have improved. Such information could have been revealed through human factors analyses. For example, human factors analyses, such as end user analysis, could have provided a more specific understanding of the degree of intuitivity required for optimal user friendliness based on who the end users were (Wickens et al., 2004). This again could have led the end users to operate the technology in a safer way. Further, informants stated that some of the errors made by the crewmembers who were not defined as end users in the project documents should have been detected previously by the designers in the design phase as possible occurrences. Thus, the product could have been designed so that crewmembers' errors, such as inputting data the wrong way or the incorrect opening or closing of valves during critical operations, were impossible to make.

In addition, if the documented end users attended only the first technical workshop, optimizing a user-friendly screen could have been challenging because the main subcontractor who was designing the screen for the drillers and the main subcontractor were not present at this workshop. Hence, they did not meet and could not exchange information at an early stage of the development process, which could have benefitted the contextual understanding for the development engineers. Furthermore, if procedure making was the other aspect in which the drillers were included, it could be viewed as a shortcoming, as the procedures were made after the product was completed and, thus, the drillers were then unable to comment on the user friendliness of the product they were to operate before it was finalized. This potentially could have been solved by using interface analyses during the process (Stanton et al., 2013) However, the project group members perceived that they were including end users at optimal phases for appropriate aspects. The project group seemed to be content with focusing on human issues, which might indicate why human factor and human reliability analyses were insufficient. If the team members were content, they would not have recognized the need for more in-depth analyses.

Regarding "*a narrow focus in different phases of the project*", we identified two important aspects. First, we found a lack of contextual understanding, as crewmembers were not considered end users. Thus, the focus was not on the remaining crew, that is, those apart from drillers and assistant drillers, in the development phase. Due to this, it was probably nearly impossible for the engineers to contemplate an unidentified element when developing the product (Schröder-Hinrichs, Hollnagel, & Baldauf, 2012; Simons & Chabris, 1999). They simply could not consider the possibility of this error before it occurred because the focus was on technological reliability, a focus that traditionally has been the most common in the offshore industry (Gordon, 1997; Gould et al., 2012; Jærnes et al., 2005; Skogdalen & Vinnem, 2011). With human error identification analysis (Stanton et al., 2013), task analysis (Kirwan & Ainsworth, 1992), and user analysis (Wickens et al., 2004), an element like this could have been avoided by training the crew, and the engineer developing the technology might have discovered the possibility of that error occurring and taken action to prevent it.

The second aspect concerns the strong focus on technology and limited focus on the end users. This is in relation to how the technology developers viewed the development process and which problems were important to solve. As Wilpert (2005) states, design could be viewed as a process of adequate problem solving because the goal of the process is to match the designer's mental model of the design object with the mental model of the future user and his or her requirements and competencies. Human factors analyses are, to a high degree, tools to promote this kind of problem solving. Nevertheless, if the engineers focused only on technical safety in problem solving when developing this technology, this aspect would not be regarded important. For example, if human factor analyses and human reliability analyses had been conducted in accordance with ISO 11064-1 (ISO 11064-1, 2000) by human factors and human reliability specialists in an early phase, such knowledge could have resulted in comprehension of which information was needed at which stages of the development process to optimize the outcome. They could have revealed the identity of the end users (Wickens et al., 2004), whose requirements and competencies could then have been considered (Wilpert, 2005).

In the current study, the developers had a general comprehension that automation leads only to less human error. However, when new automated technology is introduced, human errors tend to move to other areas (Lee, 2004), as happened in this case, too, for instance, when a crewmember opened the wrong valve at the wrong time. If conventional drilling had been used, the opening of this valve at this point would have been a correct action. This illustrates that errors can occur when people lack the training to understand the automation and the technology in general (Reason, 1990). If a user analysis (Wickens et al., 2004) had been conducted in an early phase of the development process, it could have revealed that the end users included the remaining crewmembers. Thus, a more optimal focus on who the end users were and what tasks they perform could have resulted in a focus on the end users' training to avoid mishaps due to not fully comprehending how the technology works. This rather common understanding that automation leads to less human error (Lee, 2004) might have influenced the perception that human error could not occur, which, again, could be viewed as a safety hazard. Only the drillers and assistant drillers received training that moved beyond an introduction on how to rig the new equipment. Informants explained that this was because there was less for the crewmembers to do during operations when the tasks were automated. It seems as though the tasks performed by the driller and the drilling crew was not considered when developing the new automated technology. The new tasks and need for training could have been revealed with a task analysis (Kirwan & Ainsworth, 1992) and a training analysis (Salas et al., 2006).

4.1 Reasons for Failure to Conduct Adequate Human Factors Analyses

In the current study, we argue that the outcomes of *extensive costs, low user friendliness,* and *insufficient knowledge of safe usage and potential risks of the technology by end users,* could have been reduced with the use of sufficient human factors and human reliability analyses during the development process. Analyses such as user analysis (Wickens et al., 2004), task analysis (Kirwan & Ainsworth, 1992), interface analysis, human error identification analysis (Stanton et al., 2013), and training analysis (Salas et al., 2006) could have facilitated better information coordination and brought a broad focus to the different phases of the project to enhance the possibility of a more successful outcome (PSA, 2011). Similarly, time, effort, and expense could have been saved through early intervention instead of redesigning the systems (Stanton et al., 2013). Therefore, it seems that the project team's knowledge of the analyses that should have been conducted, at what stages they should have been done, and the best way to perform the different analyses has potential for improvement. Several standards recommend conducting such analyses (e.g., ISO 11064-1, 2000; ISO 6385, 2004; NORSOK S-002, 2004; NS-EN 6140-2, 2008); thus, the question is, why were these analyses not performed? We believe that multiple elements affected this outcome.

1) Failure to perform these analyses was connected to the strong focus on technical safety and, therefore, a narrow focus on different phases of the project. From a historical perspective, this is in accordance with the fact that risk analyses has been used almost exclusively on technical systems in the petroleum industry, with little attention paid to human factors (Skogdalen & Vinnem, 2011; Vinnem: 1998).

2) The results indicate that there was an assumption that all possible technical events had been anticipated and addressed, contributing to a false sense of security (Trimpop, 1994). This could be seen in connection with high reliability organizations (HRO) (Weick & Sutcliffe, 2015) where a non-questioning culture is viewed as a safety hazard. This could be the case with the project group and the development team as well as the crew and management, who were found to have a non-questioning culture (Sætren & Laumann, 2015a). Again, this seems to be related to two aspects: First, it could be due to an overly homogeneous group, which safety theories strongly advice against (Dekker, 2011; Rasmussen, 1997; Weick & Sutcliffe, 2015). This is not recommended because not viewing aspects from several angles might contribute to important information being overlooked, which is considered a hazard. Second, it could be related to the inexperience of the subcontractors designing the screen, who believed they had received sufficient information yet were found not to have done so. When people perceive that others have control, they could become deferent, which relates to trusting others to have taken care of an issue and hence not thinking of asking questions about it

(Sætren & Laumann, 2015a). This type of deference is a warning sign in safety theories such as HRO (Weick & Sutcliffe, 2015).

3) The acceptance of technology among end users could affect the completion of human factors analyses. Throughout the development process, the end users indicated that they were happy to be a part of this new technological development (Sætren & Laumann, 2015a). This, however, could be seen in connection to willingness to change, which is the optimal factor to consider, according to several change theories (Armenakis & Harris, 2009; Cummings & Worley, 2015; Kotter, 1996). In general, change management theories are based on making people willing to change and on avoiding resistance (Sætren & Laumann, 2015b). Because these are the theories taught in management education, it is a widespread idea within change processes in organizations and management (Ghoshal, 2005), yet this may promote a non-questioning culture. In addition, the assumption that willingness and acceptance are the optimal solution might prevent scepticism because it is interpreted as resistance to change. Nevertheless, although it initially could seem cost beneficial to have people accepting the technology without question, this could result in increased costs, as in this case. Therefore, it could be seen in connection with the competing goals of cost and safety within a high-risk industry (Rasmussen, 1997).

4) The complexity of the project may have contributed to the failure to conduct human factors analyses. Interorganizational complexity has the potential to lead to misunderstandings, deference, and accidents (Milch & Laumann, 2016). Little attention has been dedicated to this aspect in the oil- and gas sector until recently (Jærnes et al., 2005), yet several of the findings in this project seem to stem from problems related to interorganizational complexity.

5) Finally, standards could affect the completion of human factors analyses. It is possible that the project group did not comprehend the importance of proper human factors analyses despite being aware of the standards. It must be pointed out that some of these regulations and standards were updated after the development phase of this particular technology. Nevertheless, the NORSOK standard S-002 (2004), for example, indicates that design shall be based on task analyses of function and that during project development analysis should be performed to ensure the potential for human error is minimized. However, neither the facilities regulations nor NORSOK standard S-002 provide thorough guidelines on which analyses should be conducted at which stages of a design project or how to perform the analyses. According to the facilities regulations,

> During design […] an analysis should be conducted of the human-machine interface, including necessary task and function analyses. The standards NORSOK S002 Chapter 4.4.5 and NS-EN 6140 Part 2 should be used for such analyses. The NS-EN ISO 11064 standard should be used for design of the central control room. NORSOK S002 Chapter 5.2.2 should be used for requirements regarding human-machine interfaces (PSA, 2011 p. 24).

In addition, the regulations state that during design, there should be a focus on human factors and human reliability. Furthermore, in terms of the facilities regulations (PSA, 2011), NORSOK S-002 (2004), and the NS-EN 6140-2 (2008), task analyses should be conducted, but none offers comprehensive details on how to do so or what outcome information such analyses should bring. Thus, we maintain that guidelines could benefit from more definite information about which analyses should be conducted in which phases of a technological development project and how the analyses should be performed. Today, several standards aim to reduce the risk of human error, yet recommendations for systematic approaches assessing these issues seem to be lacking (Demichaela, et al., 2014; Leva, Nagdahli, & Ciarapica Alunni, 2015). It could be argued that quality analyses assurance without requirements for how to perform the analyses, or what outcome they should have, has a limited function. One can observe that something is analysed, but the quality of the outcome of the analyses is possibly unclear.

Including a human factors specialist from the outset could have promoted a broader focus on safety. The project group's and the engineer development team's homogenous, superior competence involving technical aspects contributed to a lack of understanding of the need for sufficient analyses of end user requirements of the tasks that would be affected by the new technology. The decisions made by the development group in the development phase that affected the outcome, resulting in an evacuation of the platform, thus could be viewed as latent errors (Reason, 1990).

4.2 Validity

Validity is an important aspect of the discussion in a qualitative study (Elliott, Fischer, & Rennie, 1999; Kvale, 1996; Meyrick, 2006; Morrow; 2005; Yardley, 2000). In the current study, factors that could influence the validity of the results, such as the interviews being conducted retrospectively, could result in biased data. Conducting interviews in retrospect could affect the results due to the subject's memory adjustment. Nevertheless, the theme was relevant to the informants, as they still worked on the same project or in the same company with similar projects. Two of the inquired interviewees were not able to participate in the study.

Furthermore, one can never be certain whether the informants were honest or if they were saying what they thought the scientist was interested in hearing. This phenomenon could apply in the current study, too. However, after following this process for 4 years, conducting more than 40 interviews, observing the implementation process prior to, during, and after implementation, both onshore and offshore, and interviewing the crew and project members after the evacuation upon using the technology, we interpret the answers as trustworthy. Collecting the data by following informants over a longer period is said to enhance credibility in qualitative research due to elements such as being able to focus on the most important issues from several angles, meeting different stakeholders, and obtaining an in-depth understanding of the industry and issues researched (Guba & Lincoln, 1989; Morrow, 2005).

Moreover, detailed descriptions are provided to ensure the context is transparent for the reader, which is beneficial for validity (Elliott et al., 1999; Meyrick, 2006; Yardley, 2000). Transparency is important for both the research context as well as the scientific context (Elliott et al., 1999; Meyrick, 2006; Yardley, 2000). Thus, we have provided a theoretical context in the introduction in addition to a philosophical context in the method section. Nevertheless, one could question the trustworthiness of the study due to the lack of detailed description of the technology developed. However, it could be argued that it is the process of technology development and how human factors analyses were included, or not included, in this process that is studied rather than a particular technological development. Similarly, whether the results from this study are transferable to other technological development processes or are specific to this particular technology can be questioned. Because the results are based on both existing literature regarding the topic and the current longitudinal data, we argue that the results can be transferred to technological development processes in a broader spectrum.

The guidelines of Strauss and Corbin (1990) assume an objective external reality, according to the post-positivistic position they hold. Hence, the current study aimed to give the informants a voice and to represent them as accurately as possible (Corbin & Strauss, 2008).

4.3 Implications and Further Research

Based on the findings of this study, several implications could help to create a safer technological change process in high-risk industries on a practical basis, as it provides explanations of how human factors analyses potentially could prevent unwanted outcomes. In addition, it could be argued that knowledge of human factors and the benefit of a questioning culture in high-risk industries could be included in the education of engineers and managers. Furthermore, regarding scientific implications, this work has provided results that substantiate previous results on insufficient human factors analyses and its potential effects on safety. It also provides information on factors that contributed to why there were insufficient human factors analyses in a technological development process.

As a result, future research could address 1) the beneficial aspects of change management theories used in change processes in high-risk industries where safety is of importance or 2) whether projects that include human factors analyses are safer, which could further improve the theme of safety, human factors, and high-risk industries. Additionally, it would be interesting to conduct scientific research based on successful technological change processes to gain a greater understanding of success factors.

Conclusion

In the study of Sætren and Laumann (2015a), the end users trusted the developers to have an in-depth understanding of their work conditions and their competence level. This study shows, however, that this was not the case in the project investigated. In fact, developers seemed to have had little understanding of who the end users were prior to implementation and testing of the technology.

The reason for this was found to be that insufficient human factors and human reliability analyses were conducted during the development phase. Insufficient information coordination was one category found to contribute to insufficient analyses. In addition, narrow focus in different phases of the project, such as a strong focus on technical safety, seemed to be a contributing cause of inadequate human factors analyses. This lack of analyses resulted in extensive costs, low user friendliness, and insufficient knowledge on safe usage and potential risk of the technology by end users.

Based on the results of this study, we argue that performing human factors analyses throughout such a development project would benefit the project because it potentially prevents the development of cultural aspects such as non-questioning (see Sætren & Laumann, 2015a), which is regarded a safety hazard in high-risk organizations (Weick & Sutcliffe, 2007). Moreover, we argue that technological design projects would benefit from including human factors experts in the project group from the beginning of the project, as human factors analyses potentially bridge the gaps between not knowing if important information is missing and sufficient information on which to base decisions.

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References

Albrechtsen, E., & Weltzien, A. (2013). IO concepts as contributing factors to major accidents and enablers for resilience-based major accident prevention. In T. Rosendahl & V. Hepsø (Eds) *Integrated operations in the oil and gas industry*: *Sustainability and capability development.* (pp. 353–370). DOI: 10.4018/978-1-4666-2002-5

Årstad, I., Kristiansen, V., Vinnem, J. E., Wagnild, B. R., Heide, B., Nyrønning, C. A., & Karlsen, A. (2010). *Risk level in the petroleum activity: Risk of acute discharges*. Norwegian continental shelf 2001-09. Project report. Petroleum Safety Authority Norway.

Aas, A. L., & Skramstad, T. (2010). A case study of ISO 11064 in control centre design in the Norwegian petroleum industry. *Applied Ergonomics, 42*, 62–70.

Baker, J., Levenson, N., Bowman, F., Priest, S., Erwing, G., Rosenthal, I., & Wiegman, D. (2007). *The report of the BP US refineries independent safety review panel.* The B.P. U.S. Refineries Independent Safety Review Panel.

Boring, R. (2007). Meeting human reliability requirements through human factors design, testing, and modelling. *Proceeding of the European Safety and Reliability Conference ESREL 2007 –Risk, Reliability, and Societal Safety, 1*, 3–8.

Boring, R., & Bye, A. (2009). Bridging human factors and human reliability analysis. *Proceedings of the Human Factors and Ergonomics Society, 2*, 733–737.

Boring, R., Roth, E., Straeter, O. Laumann, K., Blackman, H. S., Oxstrand, J., & Persensky, J. J. (2009). Is human reliability relevant to human factors? *Proceedings of the Human Factors and Ergonomics Society 53rd Annual Meeting*.

Corbin, J., & Strauss, A. (2008). *Basics of qualitative research* (3rd ed.). Thousand Oaks, CA: Sage Publications Inc.

Cullen, L.W.D. (1993) The public inquiry into the Piper Alpha disaster. *Drilling Contractor (United States), 49,* (4).

Cummings, T. G., & Worley, C. G. (2015). *Organization development & change*. Stamford, CT: Cengage Learning.

Czaia, S. J., & Nair, S. N. (2006). Human factors engineering and systems design. In G. Salvendy (Ed.), *Handbook of human factors and ergonomics* (3rd ed., pp. 32–50). Hoboken, NJ: John Wiley & Sons, Inc.

Demichaela, M., Pirani, R., & Leva, M. C. (2014). Human factor analysis embedded in risk assessment of industrial machines: Effects on the safety integrity level. *International Journal of Performability Engineering*, *10,* 487-496.

Elliott, R., Fischer, C., & Rennie, D. (1999). Evolving guidelines for publication of qualitative research studies in psychology and related fields. *British Journal of Clinical Psychology, 38*, 215–229.

Furst, S. A., & Cable, D. M. (2008). Employee resistance to organizational change: Managerial influence tactics and leader-member exchange. *Journal of Applied Psychology*, *93*, 453–462. doi:10.1037/0021-9010.93.2.453

Ghoshal, S. (2005). Bad management theories are destroying good management practices. *Academy of management learning and education, 4,* 75–91.

Gordon, R. P. E. (1996). The contribution of human factors to accidents in the offshore oil industry. *Reliability engineering and system safety*, *61,* 95–108.

Gould, K., Ringstad, A. J., & van de Merwe, K. (2012). Human reliability analysis in major accident risk analyses in the Norwegian petroleum industry. *Proceedings of the Human Factors and Ergonomics Society,* 2016–2020.

Graham, B. et al., (2011). *Deep Water. The Gulf Oil Disaster and the Future of Offshore Drilling Report to the President.* National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling.

Guba, E.G., & Lincoln, Y.S. (1989). *Fourth generation evaluation.* Newbury Park, CA: Sage.

Ham, D. H. & Yoon, W. C. (2001). Design of information content and layout for process based on goal-means domain analysis. *Cognition, Technology & Work, 3,* 205-223.

Hollnagel, E. (2004). Task analysis: Why, what, and how. In G. Salvendy (Ed.), *Handbook of human factors and ergonomics* (3rd ed., pp. 373–383). Hoboken, NJ: John Wiley & Sons, Inc.

ISO 11064-1. (2000). *Ergonomic design of control centres part 1: Principles for the design of control centres.* International Organization for Standardization.

ISO 6385. (2004). *Ergonomic principles in the design of work systems.* International Organization for Standardization.

Johnsen, S. O., Bjørkli, C., Steiro, T., Fartum, H., Haukenes, H., Ramberg, J., & Skriver, J. (2008). *Criop: A scenario method for crisis intervention and operability analysis.* Trondheim: SINTEF Technology and Society.

Jernæs, S., Åsland, J. E., Heber, H., Morvik, R., Leistad, G., Enoksen, A. M., & Ellingsen, A. (2005). *Human factors in drill and well operations: Challenges, projects, and activities*. Retrieved 21 January 2016 from http://www.ptil.no/getfile.php/z%20Konvertert/Health,%20safety%20and%20environment/HSE%20news/Dokumenter/hfrapportengelsk.pdf

Kanter, R. M., Stein, B. A., & Jick, T. D. (1992). *The challenge of organizational change.* New York, NY: The Free Press.

Kirwan, B., & Ainsworth, L. K. (1992). *A guide to task analysis.* London: Taylor & Francis.

Kotter, J. P. (1996). *Leading change*. Boston, MA: Harvard Business School Press.

Kvale, S. 1996. *Interviews: An introduction to qualitative research interviewing.* Thousand Oaks, CA: Sage Publications Inc.

Lee, J. D. (2006). Human factors and ergonomics in automation design. In G. Salvendy (Ed.), *Handbook of human factors and ergonomics* (3rd ed., pp. 1570–1596). Hoboken, NJ: John Wiley & Sons, Inc.

Leva, M. C., Naghdali, F., & Ciarapica Alunni, C. (2015). Human factors in system design: A roadmap for improvement. *Procedia CIRP 38,* 94-99.

Luecke, R. (2003). *Managing change and transition.* Boston: Harvard Business School Press.

McCoy et al., (1999). HAZID, a computer aid for hazard identification 1. The STOPHAZ package and the HAZID code: An overview, the issues and the structure. *Trans IChemE, 77,* 317-327.

McLeod, R.W. (2015) *Designing for human reliability. Human factors engineering in the oil, gas, and process industries*. Waltham, MA: Gulf Professional Publishing, Elsevier.

Meyrick, J. (2006). What is good qualitative research? A first step towards a comprehensive approach to judging rigour/quality. *Journal of Health Psychology, 11,* 799–808.

Milch, V., & Laumann, K. (2016). Interorganizational complexity and organizational accident risk: A literature review. *Safety Science, 82,* 9–17.

Morrow, S. L. (2005). Quality and trustworthiness in qualitative research in counselling psychology. *Journal of Counselling Psychology, 52,* 250–260.

NORSOK Standard S-002. (2004). *Work environment.* Retrieved 27 May 2014 from http://www.standard.no/PageFiles/1050/S-002.pdf

NS-EN 6140-2. (2008). *Safety of machinery. Ergonomic design principles, part 2: Interactions between the design of machinery and work tasks. European Standard.* Stockholm: Swedish Standards Institute.

OGP (2013). *Offshore safety: Getting it right now and for the long term*. Retrieved 18 January 2016 from http://www.iogp.org/PapersPDF/Web_Post_GIRG_Final_300113(4).pdf

Palanque, P. A., Koorneef, F. C., Johnson, G. S., Szwillus, G., & Wright, P. C. (2004, April). Safety-critical interaction: Usability in incidents and accidents. *Extended Abstracts of the 2004 Conference on Human Factors in Computing Systems, CHI 2004* (pp. 1600–1601). Vienna, Austria. doi: 10.1145/985921.986165

Pascal, A., Thomas, C., & Romme, A. G. L. (2013). Developing a human-centred and science-based approach to design: The knowledge management platform project. *British Journal of Management, 24,* 264–280.

Paté-Cornell, M. E. (1993). Learning from the Piper Accident: A postmortem analysis of technical and organizational factors. *Risk Analysis, 13,* 215–232.

Petroleum Safety Authority (PSA). (2011). *The facilities regulations*. Retrieved 9 May 2014 from http://www.ptil.no/facilities/category400.html#_Toc345671502

Petroleum Safety Authority (PSA) (2004). *Trends in risk levels: Summary report phase 5.* Retrieved 29 January 2016 from http://www.psa.no/getfile.php/z%20Konvertert/Health%2C%20safety%20and%20environment/Trends%20in%20risk%20levels/Dokumenter/rnnstrendsinrisklevelssummarynyefigurer1.pdf

Rasmussen, J. (1991). Modelling distributed decision making. In J. Rasmussen., B. Brehmer, & J. Leplat (Eds.), *Distributed decision making: Cognitive models for cooperative work.* Chicester: John Wiley & Sons, Ltd.

Rasmussen, J. (1997). Risk management in a dynamic society: A modelling problem. *Safety Science, 27,* 183–213.

Rasmussen, M., Standal, M. I., & Laumann, K. (2015). Task complexity as a performance shaping factor: A review and recommendations in standardized plant analysis risk-human reliability analysis (SPAR-H) adaption. *Safety Science, 76,* 228-238.

Reason, J. (1990). *Human error*. Cambridge: Cambridge University Press.

Reason, J. (1997). *Managing the risks of organizational accidents.* Surrey: Ashgate.

Rouse, W. B., & Boff, K. R. (2006). Cost-benefit analysis of human systems investments. In G. Salvendy (Ed.), *Handbook of human factors and ergonomics* (3rd ed., pp. 1133–1149). Hoboken, NJ: John Wiley & Sons, Inc.

Salas, E., Wilson, K. A., Priest, H. A., & Guthrie, J. W. (2006). Design, delivery, and evaluation of training systems. In G. Salvendy (Ed.), *Handbook of human factors and ergonomics* (3rd ed., pp. 472–512). Hoboken, NJ: John Wiley & Sons, Inc.

Salvendy, G. (2006). *Handbook of human factors and ergonomics* (3rd ed.). Hoboken, NJ: John Wiley & Sons, Inc.

Sheridan, T.B. (2008). Risk, human error, and system resilience: Fundamental ideas. *Human Factors, 50,* 418–426.

Sætren, G. B., & Laumann, K. (2015a). Effects of trust in high-risk organizations during technological changes. *Cognition, Technology & Work, 17,* 131–144.

Sætren, G. B., & Laumann, K. (2015b). Organizational change management theories and safety. A critical review. Manuscript submitted for publication.

Schröder-Hinrichs, J-U., Hollnagel, E., & Baldauf, M. (2012). From Titanic to Costa Concordia—a century of lessons not learned. *WMU Journal of Maritime Affairs, 11,* 151–167.

Simons, D. J., & Chabris, C. F. (1999). Gorillas in our midst: Sustained inattentional blindness for dynamic events. *Perception, 28*(9), 1059–1074.

Shorrock, S.T., & Kirwan, B. (2002). Development and applications of a human error identification tool for air traffic control. *Applied Ergonomics, 33,* 319–336.

Sneddon, A., Mearns, K., & Flin, R. (2013). Stress, fatigue, situation awareness in offshore drilling crews. *Safety Science, 56,* 80–88.

Stamnes, Ø. N., Zhou, J., Kaasa, G-O., & Aamo, O. M. (2008). Adaptive observer design for the bottomhole pressure of a managed pressure drilling system. *Proceedings of the IEEE Conference on Decision and Control,* 2961–2966.

Stanton, N. A., Salmon, P. M., Walker, G. H., Baber, C., & Jenkins, D. P. (2013). *Human factors methods. A practical guide for engineering and design* (2nd ed.). Hampshire: Ashgate.

Strauss, A., & Corbin, J. (1990). *Basics of qualitative research: Grounded theory procedures and techniques*. Newbury Park, CA: Sage Publications, Inc.

Strøm, S. (2008). The Future Drilling Scenario. *Offshore Technology Conference*.

Taylor, J. R. (2007). Statistics of design error in the process industries. *Safety Science, 45,* 61–73.

Taylor, J. R. (2013). Incorporating human error analysis into process plant safety analysis. *Chemical engineering transactions, 31,* 301-306.

Trimpop, R. M. (1994). *The psychology of risk taking behavior.* Amsterdam: North Holland, Elsevier Science.

van de Merwe, K., Øie, S., & Gould, K. (2012). The application of the SPAR-H method in managed-pressure drilling operations. *Proceedings of the Human Factors and Ergonomics Society 56th Annual Meeting*, 2012–2025.

Wickens, C. D., Lee, J. D., Liu, Y., & Becker, G. S. E. (2004). *An introduction to human factors engineering.* Upper Saddle River, NJ: Pearson Prentice Hall.

Wilpert, B. (2005). Psychology and design processes. *European Psychologists, 10*, 229–236.

Wolfe, C. A., Morris, S. A., & Baule, A. (2009). Enhanced real-time wellbore stability monitoring using high-definition imaging with wired-pipe telemetry. *SPE/IADC Drilling Conference and Exhibition, Proceedings*, *2*, 1028–1038.

Yardley, L., 2000. Dilemmas in qualitative health research. *Psychology and Health*, *15*, 215–228.

Zimolong, B. M., & Elke, G. (2006). Occupational health and safety management. In G. Salvendy (Ed.), *Handbook of human factors and ergonomics* (3rd ed., pp. 673–707). Hoboken, NJ: John Wiley & Sons, Inc.